WATERSHED AND TUBEWELL IRRIGATION INVESTMENT IN INDIA: EVALUATION USING FINANCIAL AND ECONOMETRIC ANALYSIS

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Abstract

Negative externalities in groundwater irrigation arise due to overdraft of groundwater leading to initial and premature well failure, reduced yield, and age/life of wells. Watershed development programme aiming at recharging aquifer facilitating sustainable groundwater use is the focus of this study. Primary survey data from farmers using groundwater for irrigation in a dry land watershed in peninsular India is analysed. Results indicated that, even after considering (i) amortized cost of watershed, (ii) amortized cost per acre-inch of groundwater, (iii) electricity cost of groundwater extraction, the net returns in watershed are economically viable. This can aid policy-makers with solutions addressing the groundwater overdraft leading to negative externality with the assistance of watershed development program enhancing groundwater recharge in dryland areas in developing countries.

Introduction

Though India is one of the wettest countries, several regions are fraught with drought affecting livelihood of millions of farmers solely dependent on agriculture. In the absence of surface water for irrigation, groundwater forms a vital source in many regions. In India due to fast reducing public investment on public irrigation and the associated environmental problems, private investment on groundwater extraction has been increasing and as a result, about 60 percent of the area is irrigated currently by groundwater (IWMI 2003). With increasing vagaries in monsoonal rains and climate, farmers are not getting even one successful crop in a year. This is a *prima facie* evidence of the scarcity of water for irrigation. Marginal (less than one hectare) and small farms (between one and two hectares) have relatively little access to groundwater resource for irrigation. This constrains livelihood and income earning opportunities and is the cause for unemployment and disguised employment in farming.

According to the Indian Easement Act of 1872, groundwater rights are appurtenant to land owner *de jure*. But *de facto*, these rights are ambiguous (Chandrakanth and Arun, 1997; Chandrakanth and Romm, 1990) since in the unconfined and semi-confined aquifers of the hard rock areas, there is no surety regarding the right to a given volume of groundwater for a given number of years to any well owner, as groundwater behaves as a fugitive resource. Groundwater being an invisible resource puts researchers in nebulous state as neither its availability nor its extraction is known with certainty as both are estimated / guesstimated with several assumptions. For instance, according to the Central Water Commission (2000), in India the net draft of groundwater is 11.52 million hectare meters per year while the available groundwater for irrigation is 36.08 ml hectare meters per year, implying only 32 percent is the level of groundwater extraction. Similar is the level of groundwater extraction in Karnataka too. Thus, the official groundwater statistics present a rosy scenario of its sumptuous availability. However, the ground truth presents a different scenario. Even with this modest level of groundwater extraction, the large scale failure of shallow dug wells, increase in the proportion of deeper bore wells, reduced area irrigated per well, increasing cumulative interference among wells, depict a *prima facie* indication that the situation cannot be as rosy as the figures reveal. In addition, the position of groundwater cannot be generalized considering one or a few locations, since its potential and availability varies widely across locations as the effects of withdrawal of groundwater are felt over a period of time.

In the literature on finance and economics, better protection to environmental goods could be achieved at lower cost by replacing regulatory regimes with a system of well-defined private property rights (Coase 1937; Hardin 1968; Gisser 1983). But this requires low transaction cost of bargaining among the different stakeholders. In groundwater extraction, this is a myth as the number of extractors is increasing in leaps and bounds with the decline in rainfall in India.

Thus, assigning groundwater users particular units of groundwater stock is not plausible. Therefore, exclusive property rights, the basis for exchange economy, are difficult to establish and enforce (Young, Daubert & Morel-Seytoux 1986, p. 787). Thus, groundwater resource in hard rock areas of India can pose potential challenges for institutional innovations. The Karnataka Government prepared in detail the draft Groundwater bill on regulating the groundwater use way back in 1996. However, the same is yet to be tabled before the legislative assembly. Thus, any institutional reform in groundwater eschews the implementation part.

Even though the Government of India sought all the States for expediting groundwater regulation, a few States have progressed. Karnataka having prepared the draft groundwater bill in 1996 is yet to table on the floor of the Legislature, as political parties are apprehensive of losing electoral support from farmers, whose extraction forms more than 85 percent of groundwater use

Farmers have a perception that their access to groundwater increases by drilling deeper wells. However, groundwater availability is a function not of depth, but the degree of weathering and recharge, which are complemented by volume, and (i) intensity of rainfall, (ii) topography, and (iii) type of the soil. Recharge effort is through desiltation of irrigation tanks, land levelling and watershed development programs. In this regard, role of groundwater recharging structures like, check dams, farm ponds, percolation tanks and ravine reclamation structures is a crucial. In the areas with limited access to surface water, access to groundwater is significantly a function of recharge. Hence, watershed development programs (WDP) provide opportunities for augmenting groundwater resources.

Watershed Development Program

A watershed is an area where water drains to a common point, enabling capture of *in situ* moisture conservation. Preliminary studies have indicated that area irrigated from wells has increased after the watershed development program in a few watersheds (Table 1) in Karnataka, India (Ninan, 1997).

Table 1. Area irrigated from wells after watershed treatments in Karnataka State, India.

Watershed	Districts	Area irrigated from wells (hectares)		
		Before watershed program	After watershed program	Percentage increase
Seethanadi	Dakshina Kannada	316	371	17
Chandakavathe	Bijapur	31	35	13
Mugalikatte	Chikmagalur	95	122	28
Hirehalla	Belgaum	225	379	68
Tattihalli	Uttara Kannada	2	14	600
Doddahalla	Bidar	42	67	60
Asundinala	Dharwar	177	213	20

Source: Ninan, 1997.

Tuinhof, Attia and Saaf (2003) suggest that, recharge enhancement and increasing the storage function of the aquifer will become an important in water resources management in the coming decades. Cost of groundwater extraction and the associated transaction costs will be lower increasing equity in access to groundwater (Sastry, 1997; Diwakara and Chandrakanth, 2003; Nagaraj et al., 1999). In Karnataka State during 1997, the average cost of watershed treatment was US$ 82[1] per hectare (Sastry, 1997). This provided an incremental yield of 50 percent. The cost of providing major irrigation was $2050 per hectare, expecting to provide an incremental yield increase of 400 percent; and this cost is in the ratio of 25:1 while the returns are in the ratio of 8:1 between major irrigation and watershed development. This is the economic rationale for watershed development program in dry land areas, promoting equity in access to water resources.

Watershed treatment typically is through afforestation, construction of percolation tanks, farm ponds, check dams, ravine reclamation structures, boulder checks, rubble checks, and vegetative checks for *in-situ* moisture conservation. These structures make the running rainwater to walk, walking water to crawl, and crawling water to infiltrate to augment groundwater regime. Watershed treatments are provided from ridge to valley irrespective of the ownership of land considering technical feasibility and farmers' acceptance. This program is people centered, as participation is a crucial element in location, management, cost and benefit sharing

This study analyses the economic impact of watershed development program implemented by the Dryland Development Board of the Government of Karnataka for sustainable rainfed agriculture.

Data and Methodology

This study is conducted in Haikal Watershed in Chitradurga District, Karnataka, India. Watershed is spread over 3820 acres (1528 hectares) of which 402 acres (160.8 hectares) are irrigated forming 10.5 percent and the rest is rainfed land. The annual rainfall is 650mm occurring between May and October with a mean temperature of 36 degrees Celsius. This is included in the Drought Prone Area Program of the Government of India (Central Water Commission 2000).

Farmers were sampled after participatory rural appraisal (PRA) mapping *inter alia* of irrigation well(s), year of drilling, distance from water harvesting structures, surface water bodies like irrigation tanks, drinking water wells. The population of 65 farmers in the watershed owning irrigation well(s) is selected. After preliminary survey and pre-testing, the field data from farmers were collected using structured schedule during April 2000.

Groundwater recharge is a positive externality of watershed development program. Farmers whose irrigation wells, served and/or are serving beyond their average age, are hypothesized to have experienced/ be experiencing positive externalities. This reduces the cost per acre-inch of groundwater and the proportion of well failure.

Stratification of Farmers

Among the farmers who possessed irrigation wells in the watershed, 7 marginal farms (below 2.5 acres), 27 were small farms (2.5 acres to 5 acres) and 31 were large farms (above 5 acres) in the watershed. These farmers possessed 90 irrigation wells (80 functioning and 10 failed wells) with a majority of them were drilled after the watershed program. Bore wells were the predominant mode of water extraction. Investment on irrigation wells is a sunken cost, and obviously does not enter the decision making process. However, due to increasing probability of (premature and initial) failure of wells accompanied by declining yield of wells due to cumulative interference among irrigation wells in hard rock areas, the sunken cost becomes a recurring cost due to increased incremental costs on follow-up investments *inter alia* new additional wells, well deepening of old wells, different sites. *Ceteris paribus*, both these factors exacerbate amortized cost of irrigation as farmers invest on additional well(s) or other coping mechanisms after the initial well(s) fail to yield adequate volume of irrigation water for expected number of years. In principle, sunken cost is fixed cost and treating it as a variable cost may negate amortization[2]).

In the hard rock areas, as the average life and age of wells is fast reducing, farmers are forced to invest on new well(s) and thus fixed investments become variable costs to be amortized over the average life of irrigation wells. Thus, the presence of cumulative interference externality leads to fixed costs to be treated as variable costs due to shortened life and yield of irrigation wells thereby encouraging greater investments.

The economics of groundwater resource is usually discussed independent of watershed programs. Groom, Koundouri and Swanson (2003) discussed the economic approach to watershed management with an application in Cyprus. Kelso (1961) discussed the problem of the water stock in central Arizona. Gisser (1983) discussed the impact of assigning property rights to groundwater. Gisser and Mercado (1973) discussed the integration of economic theory of the agriculture with a hydrologic theory of groundwater. Shah, Zilberman and Chakravorty (1995) discussed the technology adoption in the presence of an exhaustible resource. Acharya and Barbier (2002) valued groundwater recharge in Nigeria, and Koundouri (2004) highlighting economics of groundwater management. In this study, economics of groundwater use within a watershed context is analysed.

Amortization Cost of Irrigation Well(s)

Accordingly, investments on irrigation well(s) have been amortized[3], considering the drilling cost, average age of the wells and an intergenerational equity interest rate of two percent. Comparing the investment on irrigation wells between different periods, this interest rate was found to be around two percent. As the method of compounding / discounting follows the usual exponential relationship between present and future values, even a modest interest rate of 4 percent, but considered over say 20 to 30 years, will outgrow the investment in leaps and bounds. This is not pragmatic, as it does not reflect the actual rate of increase in investment in well irrigation. A real interest rate of two percent covers sustainable extraction of groundwater in watershed development. However, it is worth noting the ongoing debate on use of discount factors in economic analysis.

The choice of discount rate has been a theoretical puzzle surrounding evaluation of public policies and programs[4]. An issue that divides economists and others is whether the discount rate should be in the range of 5 to 10 percent or 0 to 3 percent (Lind, 1997). One outcome of a steamy debate among economists is that *discount rate should be small* for distant futures (see, Weitzman, 1998; Gollier, 2002; Newel and Pizer, 2003; Pearce et al., 2003). A meticulous review by Pearce et al (2003) suggests that, discount rate is no longer a single number rather it varies in a declining fashion with time.

In an exercise undertaken by Chandrakanth et al (M.G.Chandrakanth, personal communication, 2006) in Karnataka revealed that the vintage of borewells at different points in time indicates the nature and degree of groundwater extraction. The depth of borewells, ranged from 80 to 150 feet in 1985, which doubled during 2001. The bore wells, yielding 3500 gallons per hour during 1985, dwindled to yield 800 gallons per hour in 2001. Further, there has been increase in irrigation pump capacity from 5 to 7.5 horse-powers (HP). In addition, farmers also consider the number of stages of pumps 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 two percent compound growth rate. This data shows that on an average for Karnataka the rate of increase in nominal investment on irrigation wells is around two percent compound growth rate and this has been taken even for amortization. In addition the fact that the real growth in investment on irrigation wells is negative. When the investments are made by farmers on irrigation wells in different years were compounded to the present, the rate of two percent offered a close approximation of the growth in the investment on irrigation wells. Further, the rate of growth in nominal investment on irrigation wells in different parts of Karnataka is two percent and hence two percent discount rate is taken in this study[5]. The two percent is the rate of investment per well. However, if we consider the investment on all irrigation wells over say 30 to 40 years divided by the number of functioning wells, as on 2006 then the investment per functioning well would have certainly increased. So if economists argue that two percent is low, it is not true. The low rate of investment per well is reasonable, but if we include externalities then it may not be economical[6].

For, dug wells, constructed during 1960s and 1970s, the investment is compounded to reflect the current costs and then amortized as:

$$\text{Compounded investment on Dug Well} = \text{DW cost}*(1+i)^{(AA)} \qquad (1)$$

Where, i = interest rate, two percent per year, DW = Dug Well, and AA = the average age of the well, computed as the difference between the year of data collection (2000) and year of well construction.

Similarly, the investment on borewell was compounded as:

$$\text{Compounded investment on Bore Well} = \text{BW cost}*(1+ i)^{(AA)} \qquad (2)$$

The compounded investment on irrigation pump set is computed as:

$$\text{Compounded investment on Pump set} = \text{Pump set cost}*(1+i)^{(AA)} \qquad (3)$$

Where, *AA* = the average age of the irrigation pumpset (about 10 years).

The above compounded investment is amortized as:

$$\text{Amortization Cost of Dug Well} = [\text{Compounded investment on dug well}*(1+i)^{AL)}*i]/[(1+i]^{(AA)}-1] \quad (4)$$

Here, *AA* = the average age of the well, the average is the difference between the year of data collection (2000) and year of well construction

$$\text{Amortized Cost of Pump set and Accessories} = \{[\text{Sum of compounded cost of pump set + pump house})*(1+i)^{(10)}*i]/[(1+i)^{(10)}-1]\} \quad (5)$$

The working life of pump set, pump house and conveyance pipe and accessories is assumed to be 10 years.

$$\text{Amortized cost of conveyance structure} = [(\text{Compounded cost of conveyance pipe used})*(1+i)^{(10)}*i]/[(1+i)^{(10)}] \quad (6)$$

Thus,

The amortized cost of irrigation well = [Amortized cost of bore well + Amortized cost of pumpset and accessories + Amortized cost of conveyance like PVC pipe + current annual repairs and maintenance cost of pump set and accessories] (7)

No energy meters using electricity to pump groundwater are installed in farmers' fields. Farmers in different parts of Karnataka are protesting against such installation since they have supplied electrical power since the 1980s free of cost. Since there are wide fluctuations in the quantity and quality of power supply 'free' power has become 'no' power to farmers in Karnataka. In addition, the Electricity authority has not been able to uniformly enforce collection of dues from other defaulters. Farmers are asked to pay a flat rate for the electricity used at the rate of around $ 11 per Horse Power of pumpset per annum. For an average pumpset capacity of 5 HP, this amounts to $55. Farmers did not pay flat electricity tariffs too and this is a political economy question as farmers expect this to be a subsidy. Chandrakanth et al (2001) estimated that to pump one acre-inch of groundwater it approximately needs energy of 42 kilo watt hours valued at US $ 1(at 1 rupee per Kilo watt hour). The question of whether cost of electrical power to farmers forms a substantial portion of the pumped cost of groundwater or not depends upon the amortized cost of groundwater and is relevant, since it entirely depends upon (i) the level of negative externalities due to groundwater overdraft and (ii) level of positive externalities due to watershed treatments on groundwater recharge. In this study, the amortized cost per acre inch of groundwater varies from $1.94 to $ 5.21. For farmers incurring $1.94, the electricity cost per acre-inch would be colossal compared to farmers incurring $5.21. Largely in hard rock areas, due to increasing failure rate of irrigation wells, the implicit costs of well failure due to externalities are becoming far higher than the electricity subsidy offered to farmers and thus electricity subsidy is not a windfall gain to farmers in such areas.

Estimation of the age of well is crucial as it subsumes effect of watershed treatments. The wells, which serve beyond the average age, would have been benefited due to positive externality despite cumulative interference. The wells that serve below the average age is assumed to be affected due to negative externality due to cumulative well interference. The average age ultimately reflects the externalities due to watershed program.

Net Returns

Net returns are estimated using gross returns, costs and amortization cost of irrigation wells for all the wells on the farm. Farms are classified based on the gross area irrigated possessed and the volume of water extracted for irrigation. To study the equity implications, farmers are classified based on the location of their well(s) in relation to water harvesting structures in the watershed, the amortized cost per acre-inch of water, gross area irrigated, well yield and net returns.

Annual Externality Cost

The externalities associated with groundwater have been documented theoretically and empirically (Dasgupta, 1982; Provencher and Burt, 1994a and 1994b; Gisser, 1983; Gisser and Sanchez, 1980; Eswaran and Lewis, 1984; Provencher and Burt, 1993; Groom and Swanson, 2003). In this study, well failure externality is defined as declining yield of the well or well becoming dry due to cumulative well interference, and not due to faulty location of wells or low rainfall. The effect of cumulative well interference on yield of the well can be sudden or gradual. If the effect is gradual, then the interfered well begins to experience declining yield over a period of time, if the effect is sudden, then the interfered well suffers from initial failure.

The annual externality cost (AEC) of irrigation is estimated as the difference between the amortized cost per well and the amortized cost per working well as

$$\text{AEC} = \text{Amortized cost per well} - \text{Amortized cost per working well} \quad (8)$$

If the amortized cost per well (considering all the wells on the farm) is equal to the amortized cost of working well, then all wells are functional and there are no failed wells on the farm and thus no externalities. If the failure rate of wells is high, then the gap between the amortized cost per well and that per working well would also be large as the cost of well failure due to interference would be apparent and hence the externality cost

Economics of Irrigation

Amortized cost per acre-inch[7] of groundwater is obtained by dividing amortized cost of irrigation well by total groundwater used on farm. The cost of cultivation for each crop on the farm is obtained as the expenditure on human labour, bullock labour, machine hours, seeds, fertilizers, plant protection chemicals, manure, transportation and bagging, and the amortized cost of groundwater besides the opportunity of working capital. The opportunity cost of working capital is computed at 10 percent. Cost of production is, cost of cultivation + amortized cost of irrigation + interest on variable cost + opportunity cost of dry land agriculture. The opportunity cost of dry land agriculture is the average net return obtainable from that area of land devoted to irrigation, if that land were to be cultivated on rain fed basis. The Gross Cropped Area (GCA) is the sum of area under crops in all the three seasons (Rainy, winter and summer) + Area under dryland crops. The Net Cropped Area (NCA) is the sum of area under all crops in rainy season; Gross Irrigated Area (GIA) is the sum of irrigated area under all crops in all the seasons. Net Irrigated Area (NIA) is the irrigated area under all crops in rainy season. The cropping intensity (CI) is computed as [Gross Cropped Area / Net Cropped Area] X 100 and the Irrigation Intensity (II) is computed as [Gross Irrigated Area / Net Irrigated Area] X100. Gross returns for each crop are the value of the output at the prices realized by farmers (during 1999-2000 agricultural year). Net return from well irrigation is the gross return from irrigated area minus cost of production of all crops.

Equity in Access

Equity is a vital aspect in the study of economics of watershed management and emphasizes on what classes of farmer are benefited from watershed program (Chandrakanth and Diwakara 2001). In order to capture the synergy involved in the role of watershed structures in augmenting the groundwater recharge farmers are classified with the hypothesis that wells located within 800 feet from water harvesting structures have fairly reasonable well yield compared to wells located more than 800 feet. The water yield of wells in proximity to water harvesting structure, cost of water per acre-inch and the gross area irrigated are considered for equity analysis.

In addition to amortized cost per acre-inch of groundwater extracted, amortized cost of watershed development program is considered by amortization of the total cost of watershed across the total water used by all farms for 20 years, assuming that benefits from watershed development project span over 20 years[8].

Groundwater in hard rock areas is largely dependent upon the degree of natural recharge through rainfall and percolation and human efforts through efforts *inter alia*, desiltation of irrigation tanks, soil and water conservation, bunding, contour bunding, contour ploughing, construction of farm ponds, percolation ponds, ravine reclamation structures, gully checks, which form a part of the watershed development program. According to the latest Minor Irrigation Census of Karnataka,9in Karnataka, 92 percent of dug wells and 95 percent of borewells are outside the command area of surface water bodies. Thus a vast majority of the irrigation wells as well as drinking water wells suffer from low recharge. With absolutely no initiative from farmers to recharge groundwater, Watershed Development Projects / Programs are the only public funded programs which are responsible for groundwater recharge. These programs are implemented with the participation from farmers and function for a period of five years. Since *insitu* moisture conservation is the key component of watershed program, farmers' commitment to maintain watershed structures influences the performance of the watershed program. This apparently influences the groundwater recharge, which in turn influences the 'life' and 'age' of irrigation wells. 'Life' of well refers to well/s, which already served and are no longer functioning at the time of field data collection, and includes wells, which failed initially, prematurely and wells, which functioned for their normal or average life and beyond. 'Age' refers to the well/s, which is functioning at the time of field data collection. Thus, there are two averages – the average life and average age. As initial failures of irrigation wells gives the life as zero, if a majority of wells have initial failure, then amortized cost will be infinity. Thus, to avoid such an extreme, both 'life' and 'age' of wells are clubbed to find the average 'life' or 'age'. In watersheds where there is commitment of farmers for maintenance of watershed structures, with good rainfall, both the 'age' and 'life' of wells would increase. However, as the impact of the watershed development program is over a period of time, not apparent but implicit, the discount rate is low. The low discount rate, in watershed programs is reflected in (i) relatively poor commitment of farmers in maintaining the watershed structures, after the project/program is over and (ii) low or no willingness to pay for maintenance of watershed structures. These are not unusual for a tropical rainfed agricultural area, since efforts to form effective 'water user associations' of farmers in the relatively better endowed surface water irrigated areas, to transfer the responsibility of water use, management and collection of water rates under Participatory Irrigation Management (PIM), have seldom been fruitful.

Physical Access to Groundwater

Physical access is analysed regressing groundwater used per acre of gross irrigated area as a function of average well depth, distance of well to water harvesting structure and well yield and amortized cost per acre-inch of groundwater. It is hypothesised that physical access to groundwater varies directly with well depth, distance from water harvesting structure, well yield and inversely with amortized cost of groundwater per acre-inch in the log-linear relation:

$$\text{Ln } WU = \ln \alpha + \beta_1 \ln WD + \beta_2 \ln WDWHS + \beta_3 \ln WY + \beta_4 \ln CW \quad (9)$$

Where, α = intercept, β's = coefficients, WU = Water used per acre of gross area irrigated, WD = Well depth (feet), WDWHS = Well distance from water harvesting structure (feet), WY = Water yield of the well (gallons per hour), and CW = Cost of water (dollars per acre-inch of water).

The hypothesis that the groundwater used on the farm directly varies with consumptive use of groundwater by onion crop is tested with the log-linear equation:

$$\text{Ln } WUI = \ln \alpha + \beta_1 \ln WUO \quad (10)$$

Here, WUI = Total groundwater used on the farm (acre-inches), WUO = groundwater used for onion crop on the farm (acre-inches). Onion crop relatively consumes more water compared with all other crops.

Economic Access to Groundwater

The economic access to groundwater is measured by amortized cost of groundwater per acre-inch and is hypothesised to vary inversely with well depth, directly with well distance from water harvesting structure and inversely with water yield from the well and gross irrigated area. The economic access to groundwater is regressed on well distance from water harvesting structure (in feet), water yield for the well (in Gallons per hour), and gross irrigated area (in acres). The estimated function in log-linear form is

$$\text{Ln CW} = \ln \alpha + \beta_1 \ln \text{WY} + \beta_2 \ln \text{WDWHS} + \beta_3 \ln \text{GIA} \quad (11)$$

Here CW = Amortized Cost of groundwater (dollars per acre-inch), WY = groundwater yield from the well (Gallons per hour), WDWHS = Distance of well from water harvesting structure (feet), and GIA = Gross irrigated area (acres).

Net returns per farm are regressed with amortized cost of groundwater per acre-inch, total groundwater used for irrigation on the farm, and total labour used on the farm using the log-linear form:

$$\text{Ln NRPF} = \ln \alpha + \beta_1 \ln \text{CW} + \beta_2 \ln \text{WUI} + \beta_3 \ln \text{LAB} \quad (12)$$

Here, NRPF = Net returns per farm (dollars), CW = Amortized Cost of water (dollars per acre-inch of water), WUI = Total groundwater used for irrigation on farm (acre-inches), and LAB = Total labour on the farm (man-days). The net return per farm is hypothesized to vary inversely with the cost of water, directly with the labour used and water used for onion crop on farm.

Results and Discussion

In Haikal watershed program, 44 check dams, 13 ravine reclamation structures and 10 rubble field checks were constructed. The total investment of watershed treatment was US[10] $ 64794. The amortized cost of watershed treatment forms around $7897 (amortized at two percent for 20 years assumed to be the life of the watershed). The cost of training farmers formed 0.23 percent of the total cost of the watershed treatments and administrative cost formed 0.22 percent. The cost of watershed per acre-inch of water is $ 0.65 (see Table 2).

Table 2. Details of Water Harvesting Structures Constructed and Investment in Haikal watershed, Karnataka, India

Particulars	Numbers	Investment (US dollars)
Check dam	44	26.96
Ravine Reclamation Structures	13	2.95
Rubble Field Checks	10	2.22
Training Cost		153.84
Administrative Cost		143.58
Total cost of watershed treatments		64779

Amortization cost of watershed	7897
Amortized Cost of watershed treatment per acre-inch of water	0.65

Source: Dry Land Development Board, year 2005, Chitradurga District, India
Notes:

a) Amortized cost of watershed is calculated at a modest rate of 2 percent interest rate for amortization for 20 years, considered as the life of the watershed development project.

b) Amortized cost of watershed treatment per acre-inch of water is calculated by dividing the total water used for irrigation by the sample farmers Even though the current water extracted in the watershed is around 6000 acre-inches, the total water used is projected at 12000 acre-inches assuming that the water used will be doubled in due course.

Irrigation Wells Before and After Watershed

Among the 90 irrigation wells in the watershed, 80 wells were functioning and 10 wells (11 percent) were not. This failure rate of 11 percent fares better than that of 40 percent estimated for the Eastern Dry Agroclimatic Zone (Nagaraj, Chandrakanth and Gurumurthy, 1994).

However, it is important to note that the volume and quality of groundwater for irrigation is highly location specific and it depends on *inter alia* hydrogeological characteristics. India has a varied hydrogeological setting. The entire state of Karnataka excepting coastal region is classified as hardrock area for hydrogeological purposes. The major types of rocks are gneiss, granite, basalt, and schist. The schists have low groundwater yielding capacity. The study area of Haikal watershed in Chitradurga District is largely composed of crystalline schists, granitic gneisses and the newer granites with a few later intrusive basic dykes belonging to the oldest rock formations in India. Granitic gneisses forms occupy more than 50 percent of Chitradurga district (Mysore State Gazetteer, 1967, pp.11-12). In eastern dry zone where the well failure rate is high, the major type of rocks include, lateritic masses occurring as irregularly distributed patches in the form of flat hills (Chandrakanth, Adhya and Ananda, 1998).

It is crucial to note that the number of wells mushroomed from 8 to 78 before and after the watershed program and in addition, more than 97 percent of them are functioning. That the watershed development program has been able to attract this impressive level of private investment from farmers to drill irrigation wells in itself is a pointer to the positive externalities of the watershed program. This is also a *prima facie* evidence of synergistic effects of watershed treatment to groundwater recharge resulting in positive externalities (refer to Table 3).

Table 3. Irrigation Wells Before and After watershed, Haikal DPAP Watershed, Karnataka, India

Particulars	Before watershed		After watershed	
	Functioning	Non-functioning	Functioning	Non-functioning
Dug well	0	2	0	2
Bore well	8	6	78	6
Dug-cum-bore well	0	2	2	2
Total	8	10	80	10

Source: Field Survey 2005

Distribution of Irrigation Wells

Considering the population of farmer who possessed irrigation wells in the watershed, 53 percent belonged to marginal and small farm category (landholding below 5 acres). Considering the distribution of functioning wells and amortized cost of all wells, 44 percent of farmers belong to marginal and small category and 56 percent belong to large category. The amortized cost per functioning well is uniform across all classes of farmers ($82). The large farmers have an economic advantage, as their proportion of functioning wells is higher than other classes.

The negative externality (cost) per well is a modest $ 9.6. The marginal farmers incurred no externality cost, since they did not face failure of irrigation wells. With this low level of externality, the effect of cumulative interference is low. It was indicated by farmers that it is after Haikal watershed program in 1994, they began tapping groundwater for irrigation on a relatively larger scale. In the process, farmers faced a modest failure rate of (11 percent of) irrigation wells. This rate of failure is low and is due to watershed development program contributing to groundwater recharge (Table 4).

Table 4. Details of irrigation well(s) in the Haikal DPAP watershed, Karnataka State, India

Particulars	Marginal Farms	Small Farms	Large Farms	All Farms
Number of farmers	7	27	31	65
	(10.8)	(41.5)	(47.7)	(100)
Total number of wells	7	31	52	90
	(7.8)	(34.4)	(57.8)	(100)
Number of functioning wells	7	28	45	80
	(8.8)	(35)	(56.3)	(100)
Number of non-functioning wells	0	4	6	10
	(0.0)	(40)	(60)	(100)
Total investment on all wells on all farms ($)	7010	2593	39495	72442
	(9.7)	(35.85)	(54.5)	(100)
Investment on well irrigation per farm ($)	1001	960	1274	1078
	(30)	(29)	(41)	(100)
Amortized cost of all wells per farm ($)	688	2519	3753	6961
	(9.9)	(36.2)	(53.9)	(100)
Amortized cost per well ($)	98	81	72	77
	(36.2)	(33.1)	(30.7)	(100)
Amortized cost per functioning well ($)	98	90	83	87
Annual externality cost per well ($)	0	8.7	11	9.6

Notes:

a) Marginal farms: < 2.5 acres; Small farms: 2.51 to 5 acres; Large farms: > 5.1 acres.

b) As the population of irrigation wells consisted of 65 wells, all have been considered in this study and hence this is a population study.

c) The annual externality cost is taken as the difference between the amortized cost per well and the amortized cost per functioning well.

d) The figures in parenthesis indicate percentage to the total.

Distribution of Area Irrigated

Considering the vintage of functioning wells, 98 percent were bore wells drilled in the early nineties. About 75 percent of gross irrigated area (GIA) is with large farmers, 23 percent with small farmer and marginal farmers have two percent. Even though the watershed development program facilitated physical access to groundwater resource, economic access in terms of gross irrigated area is skewed. The gross irrigated area per functioning well for large farmers is 17.93 acres, while that for small farmers is 8.79 acres and 4.85 acres for marginal farmers. Large farmers thus have 4.5 (=18/4) times higher physical access to irrigation and small farmers have 2 (=8/4) times higher physical access than marginal farmers (Table 5).

Table 5. Distribution of wells and Area irrigated and in the
Haikal DPAP Watershed, Karnataka, India

Type of irrigation well(s)	Marginal Farmer		Small Farmer		Large Farmer	
	No.	GIA (acres)	No.	GIA (acres)	No.	GIA (acres)
Bore well	7	34	28	246	41	801
Dug well	0	0	0	0	2	4
Dug-cum-bore well	0	0	0	0	2	2
Total	7		28	246	45	807
Average gross irrigated area per functioning well (acres)	4.85		8.79		17.93	

Note: GIA = gross irrigated area, No. = number

Assuming that distribution of groundwater use follows normal distribution, mean plus or minus one time the standard deviation includes 66 percent of the farmers. Accordingly, farmers were classified as those using up to 4.4 acre-inches of groundwater per acre as in ‘low water regime’, those using between 4.41 and 6 acre-inches as in ‘medium water regime’ and those using beyond 6.1 acre-inches as in ‘high water regime’.

Results indicated that large farmers in all the three water use regimes have the largest access to groundwater ranging from 65 percent in the last category to 81 percent in the second category (Table 6).

Table 6. Physical Access to Groundwater for Different Classes of Farmers

Particulars	Low water accessibility regime			Medium water accessibility regime			High water accessibility regime		
	MF	SF	LF	MF	SF	LF	MF	SF	LF
No of functioning wells	3 (15)	5 (25)	12 (60)	2 (6)	8 (26)	21 (68)	2 (5)	17 (46)	18 (49)
Average Depth of the well (feet)	202	220	244	150	153	189	203	134	155
Distance to WHS (feet)	233	383	509	300	371	625	1300	390	659
Average Yield of the Well (Gallons per hour)	2013	2425	2743	2227	2196	2120	2080	2138	2173
Total water used on all the farms (acres inches)	64 (9)	141 (20)	509 (71)	41 (2)	377 (17)	1845 (81)	56 (2)	1020 (33)	2005 (65)

Notes:

(a) Figures in parentheses indicate percentage to the total.

(b) MF = Marginal Farms, SF = Small Farms, LF = Large Farms.

(c) Low water accessibility regime is farmers using up to 4.4 acre-inches per acre of irrigated area, Medium water accessibility regime: 4.41 to 6 acre-inches, and High water accessibility regime: > 6 acre-inches.

From regression analysis, it was found that well yield has positive (elastic) influence on volume of groundwater used while cost of groundwater exerted negative (inelastic) influence. The results show that for one percent increase in groundwater yield per well, the groundwater used per acre increased by 1.48 percent, while for one percent increase in cost of groundwater, the groundwater used declined by 0.29 percent. The distance to water harvesting structures had no significant influence on well yield. About 80 percent of all the irrigation wells were located within a distance of 800 feet from water harvest structures and majority of the irrigation wells were recharged (Table 7).

Table 7. Dependence of Physical Access to Groundwater on Irrigation Well Variables

Variables	Coefficients	t-Statistics	R^2
Intercept	-7.39	-1.708	0.30
Well Depth (feet)	-0.122	-1.352	
Well distance from WHS (feet)	-0.022	-0.69	
Well Yield (GPH)	1.479*	2.68	
Cost per acre-inch (dollars)	-0.297	-3.08	

Notes:

a) *Significant at 1 percent level
b) WHS = Water Harvesting Structures, GPH = Gallons per hour
c) Dependent variable is groundwater used per acre of gross irrigated area (acre-inches).

A one percent increase in groundwater used for onion crop, indicated that physical access (in terms of total groundwater used on the farm) increased by 0.34 percent. Thus, the demand for groundwater increased with cultivation of high value commercial crop. The results were significant at 1 percent level with an R^2 of 0.82. Thus, onion crop economics has significant impact on total groundwater used on the farm (Table 8).

Table 8. Influence of water used for onion crop on total water used on Farm in Haikal DPAP watershed, Karnataka, India

Variables	Coefficients	t-value	R^2
Intercept	3.156	21.37	0.82
Independent Variable:			
Water used for onion crop (acre inches)*	0.339	8.18	

Notes:

a) Dependent Variable is Logarithm of groundwater used per farm (acre-inches)

b) Independent variable is logarithm of groundwater used for onion crop per farm

c) Significant at 1 percent level

Groundwater Benefits across Different Water Accessibility Regimes

In the ‘low water regime’, large farmers with access to 71 percent of groundwater and 55 percent of GIA used 4.4 acre-inches of water per acre and realized 60 percent of net returns. The shares of marginal and small farmers in realizing net returns were 30, 42 and 54 percent respectively in the three regimes. The net return per acre-inch of groundwater was higher for small and marginal farmers compared with large farmers. The marginal and small farmers using more than 6 acre-inches of groundwater realized 10 percent of the total net returns with less than 37 percent of total GIA.

Large farmers across all water accessibility groups have a larger share of the total groundwater used on the farm than other groups of farmers. Marginal and small farmers using up to 4.4 acre-inches of water per acre realized 40 percent of the total net returns in this group possessing 45 percent of the GIA. Marginal and small farmers in the second group (using 4.41 to 6 acre-inches) realized 64 percent of the total net return with 37 percent of GIA. Marginal and small farmers in the third group (using more than 6 acre-inches of water per acre) realized 54 percent of total net return possessing 45 percent of GIA (Table 9 and Fig. 1).

Table 9. Benefits Accrued from Groundwater usage for Irrigation for Farmers across Different Water Accessibility Regimes

Particulars	Low water accessibility regime			Medium water accessibility regime			High water accessibility regime		
	MF	SF	LF	MF	SF	LF	MF	SF	LF
No of farms	3 (22)	5 (35)	6 (43)	2 (10)	6 (30)	12 (60)	2 (6)	16 (51)	13 (43)
Water used per acre of GIA (acre-inches)	4 (36)	4 (36)	3 (28)	5 (31)	6 (38)	5 (31)	7 (33)	7 (33)	7 (34)
Total water used across all farms (acre-inches)	64 (9)	141 (20)	509 (71)	41 (2)	377 (16)	1845 (82)	56 (2)	1020 (33)	2005 (65)
Gross irrigated area (acres)	6 (19)	8 (26)	17 (55)	4 (9)	10 (23)	27 (64)	4 (11)	9 (26)	22 (63)
GIA per functioning well (acres)	6 (22)	8 (30)	13 (48)	4 (14)	8 (28)	16 (58)	4 (14)	9 (33)	15 (53)
Total net returns across all farms ($)	443	748	2733	556	2887	4456	1052	5687	5682
Net returns per farm ($)	147 (19)	148 (20)	455 (61)	278 (24)	481 (42)	371 (34)	526 (40)	355 (27)	437 (33)
Net returns per acre of GIA	24.6	20	35	69	48	23	131	39	29
Annual net returns per acre-inch of water ($)	7	5.25	5.3	13.5	7.6	2.4	18.7	5.5	2.8
Amortized cost of irrigation per acre-inch ($)	5.2	3.9	1.9	4.8	2.4	1.5	4.6	2.0	1.3
Economic access to groundwater = acre-inch of water used for irrigation per dollar of amortized cost of well	0.190	0.248	0.487	0.204	0.414	0.648	2.135	0.487	0.726

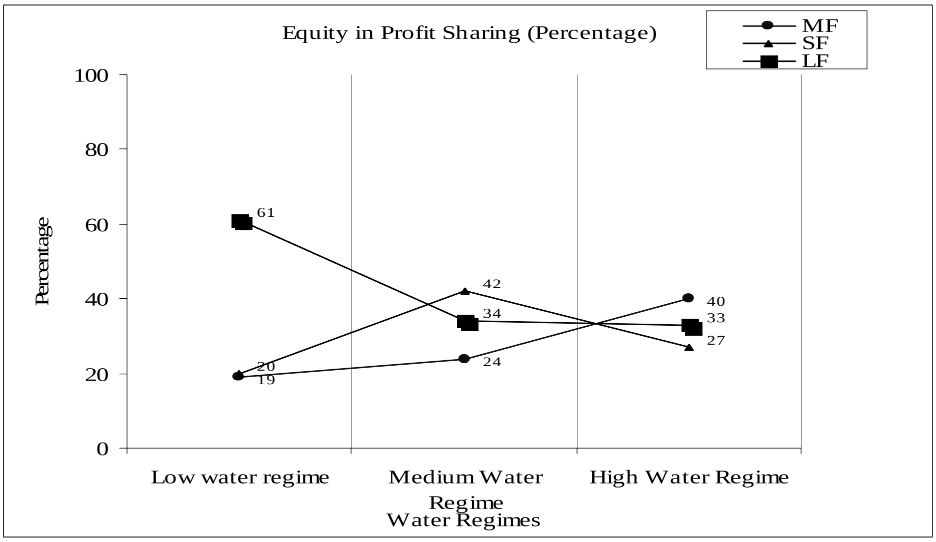
Notes:

(a) GIA = gross irrigated area

(b) MF= Marginal Farms, SF = Small Farms, LF = Large Farms.

(c) Low water accessibility regime = up to 4.4 acre-inches, Medium water accessibility regime = 4.41 to 6 acre-inches, and High water accessibility regime = >6 acre-inches.

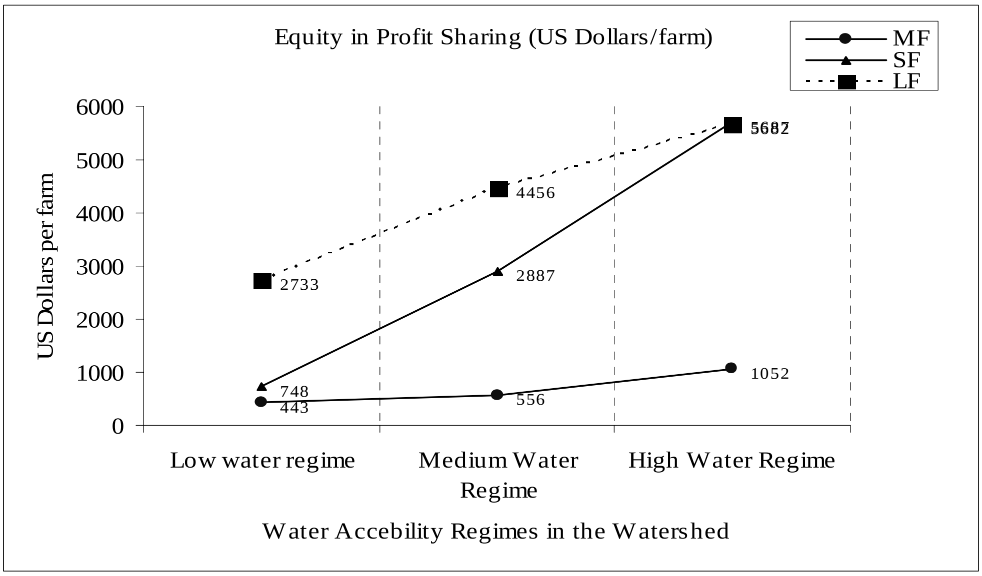
Figure.1 Equity in Profit Sharing (percentage) Across Farms and Water Accessibility Regimes



Note: MF = Marginal Farmers; SF = Small Farmers; LF = Large Farmers

Economics of groundwater use indicated that marginal farmers garnered 40 percent of the net returns per farm compared with 27 percent by small, and 33 percent by large farmers respectively in high water regime (Fig.1). Further, small farmers are as relatively efficient as large farmers are as they shared equal amount of net return per farm ($5687 for small and $5682 for large farmers (Fig.2).

Figure.2 Equity in Profit Sharing (US Dollars/farm) Across Farms and Water Accessibility Regimes



Note: MF = Marginal Farmers; SF = Small Farmers; LF = Large Farmers

Economic Access to Groundwater

Economic access to groundwater increased with yield of irrigation well, reduced with the distance of well from water harvesting structures and increased with the gross irrigated area. This is a pointer to bringing water use efficiency through adoption of water saving technologies and thereby expands the area under irrigation. For a one percent increase in well yield, the economic access increased by 0.51 percent. For a one percent increase in the gross irrigated area, economic access increased by 0.35 percent. For a one percent increase in well distance from the water harvest structures, economic access to groundwater reduced but this effect is not significant. The R^2 is 0.53 (Table 10).

Table 10. Dependence of Economic Access to Groundwater

Variables	Coefficients	t-Statistics	R^2
Intercept	-9.52	-2.38	0.53
Well yield (GPH)	0.51	0.98	
Well distance from WHS (feet)	-0.041	-1.37	
Gross irrigated area (acres)	0.35*	7.81	

Notes:
(a) * Significant at 1 percent level
(b) GPH = Gallons per hour, WHS = Water harvesting structures
(b) Dependent variable = Natural logarithm of (1/cost per acre-inch of water)

The net return per farm is regressed on the amortized cost per acre-inch of irrigation, volume of groundwater used and labour used. Net returns up to $1134.65 (Rs. 55314) (anti log of intercept value) are influenced by factors like land, capital and other inputs not considered in the regression. For a one percent increase in groundwater used net return increased by 0.53 percent. For a one percent increase in cost per acre-inch of groundwater, net return reduced by 0.72 percent, both being inelastic (Table 11). This lends support to previous findings that (in areas where negative externalities due to groundwater overdraft are not apparent) the main variable affecting net revenue in a farming system is the pumping cost (Kelso 1961).

Table 11. Dependence of Net Returns per Farm on Water and Labour Variables

Variables	Coefficients	t-Statistics	R^2
Intercept	10.92	4.53	0.71
Cost per acre-inch of water (dollars)	-0.72*	-1.95	
Water used on the farm (acre-inches)	0.53*	2.24	
Labour on the farm (man days)	0.37*	2.90	

Notes:
a) Significant at 1 percent level
b) WHS = water harvesting structures,
c) Dependent variable: Log of (1/cost per acre-inch of water)

Considering total groundwater used on the farm, marginal and small farmers together used 50 acre-inches when compared with 141 acre-inches by large farmers. This is obvious as large farmers have higher gross irrigated area as demonstrated earlier. The net return per farm is almost three times higher ($ 8054.48) for large farmers than their counter parts ($2741.78). The cost of groundwater per acre-inch is one and a half times higher for small farmers compared to large farmers. The results are statistically significant (Table 12).

Table 12. Statistical Significance of Groundwater Benefits

Particulars	Mean		Standard Deviation		t-value
	Marginal and Small Farmers	Large Farmers	Marginal and Small Farmers	Large Farmers	
Total water used on the farm (acre-inches)	50	141	22.38	110.46	4.55**
Net Returns per farm ($)	2741.78	8054.48	2187.15	5648.45	5.08**
Net Return per acre of Gross Irrigated Area ($)	334.31	415.24	212.	02169.35	1.70*
Net Returns per acre-inch of water ($)	51.95	61.16	30.33	32.20	1.13
Cost per acre-inch of water ($)	3.69	2.44	1.43	0.70	4.61**

Notes:

a) ** Significant at 1 percent level; *Significance at 5 percent level

Concluding Remarks

Watershed impact on farm economy is apparent, as most of the irrigation wells drilled after the watershed development program are functioning. This was even evident during field visit, as farmers had positive attitude toward drilling new well(s) due to watershed program. Further, the amortized cost of groundwater here is lower ($2.42) compared with $ 51.46 per acre-inch of groundwater in non-watershed area in Shimoga district in the southern State of Karnataka (Basavaraj, 1998). Large farmers by virtue of their larger gross irrigated area are reaping larger proportion of the net returns, compared to marginal and small farmers. The well failure rate is a meagre 11 percent when compared with the corresponding failure rate of 40 percent in eastern dry zone of Karnataka state. About 56 percent of the beneficiaries belong to marginal and small farmers.

Watershed treatment has enhanced groundwater availability through groundwater recharge with positive spill overs by (i) reducing the cost of groundwater used for irrigation (i) reducing negative economic externality due to well interference; (iii) increasing physical access (water used per acre of gross irrigated area) to groundwater resource for irrigation through groundwater recharge. In all the three-groundwater accessibility regimes, the large farms by virtue of their larger gross irrigated area garnered a larger proportion of the net returns. The watershed program facilitated cultivation of high value crops (like, onion) by those farmers who were cultivating low value crops before the watershed program, thereby improving their economic position.

Thus, watershed development program is a means to reduce the negative externalities due to frequent well failure in dryland areas. Watershed development program with the objective of groundwater recharge is a viable policy option for the development of dryland areas. Such programs must be embedded in the National Water Policy to ensure effective and equitable implementation in the needy regions of India. Nevertheless, farmers need to be cautious regarding judicious use of groundwater since they need to respect all farmers' needs who have right to tap and use groundwater, but are precluded due to low economic access. Therefore, there is a need for a blend of policies to focus on (i) allocation of groundwater on annual/season/crop basis, (ii) regulating extraction through permissible annual extraction, through water metering (iii) restriction on number of wells drilled on the farm, and (iv) provision of sale of water entitlements when it is surplus to a needy neighbouring farm and (v) promotion of groundwater markets. Nevertheless, farmers need take collective action to maintain the water harvesting structures to enhance the sustainable recharge of the aquifer.

However, it is to be considered that, the proposed policy instruments for managing groundwater depends on the allocation of rights for extraction. Finally, even though private net returns are economically viable in the watershed the groundwater is still underpriced, not reflecting the true value. This implies that farmers maximize private net benefits and pump water until its marginal net benefit is zero (Hellegers and van Ierland, 2003). Hence, we suggest considering pro-rate charging of electricity. Other scholars have expressed similar views (Diwakara and Nagaraj, 2003; Shah, 1993; Moench 1996, Nagaraj, Marshall and Sampath, 1999).

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Footnotes

[1] The cost of watershed treatment was Rupees 4000 per hectare, was converted to US dollars based on an average exchange rate of 1USD = 48.75.

[2]. For instance, Coase (1946) argues that, the fixed costs are in fact outlays which were made in the past for factors, the return to which in the present is a quasi-rent, and a consideration of what the return to such factors ought to be raises the problem of great intricacy (p.170). Also, see Coase (1970) on marginal cost pricing.

[3] The amortization cost does not include a uniform life span year's "t" over which all cost has been amortized. This limitation has been ignored for analysis purpose.

[4] We thank the Editor and an Associate Editor of this journal for highlighting this point, which led to review of recent literature on social discounting, especially Pearce et al (2003), Weitzman (1998), and Gollier (2002).

[5] Although there is uncertainty about everything in the future, the use of two percent discount rate reflects the actual rate of increase in investment in well irrigation.

[6] The externalities can be estimated by dividing the investment on all wells by only the number of functioning wells.

[7] One acre-inch of groundwater has 22,611 gallons of water.

[8] The life of the watershed project is assumed 20 years. However, this depends upon the commitment of farming community in maintaining the watershed over such a long period.

[9] Water Resources Informatics Division, National Informatics Centre, New Delhi, 2005.

[10] The average exchange rate of one US dollar is assumed to be 48.75 Indian rupees.