Is it possible to revive dug wells in hard rock India through recharge?
Discussion from studies in ten districts of the country

Sunderrajan Krishnan, Rajnarayan Indu, Tushaar Shah,
Channappa Hittalamani, Banderrao Patwari, Deepak Sharma, Laxman Chauhan, Vivek Kher, Hirudia Raj, Upendrasinh Mahida, Shankar M and Krishna Sharma

ABSTRACT

Groundwater exploitation in hard rock India is leading to high distress amongst farmers. Various water conservation schemes have been tried and piloted, but no idea has scaled up to the national level. Groundwater use, individual as it is, an idea of revitalizing it, if still individual-based, could possibly succeed. Recharging through dug wells is one such thought. After mass movements in Saurashtra in mid 1990s, no effort has been made to promote the idea nationally, till now. The current national programme on artificial dug well recharge hopes to do so. But this idea can succeed only if farmers see a worth in it and try to make it successful. A survey of 767 dug wells owning farmers in 10 districts of India shows that there is immense potential, yet constraints to dug well recharge. A comparison with the average natural recharge over hard rock areas of 116 mm annually shows that from collected data there is almost an equal potential in recharging groundwater irrigated areas through dug wells. Surveyed farmers also expect a great increase in water availability, especially during the dry seasons. However, farmers are wary of this recharged water flowing across to their neighbours. They expect to gain around 30% from their recharged water, but agree that there would be a common gain by recharging together along with their neighbours. The estimated cost by farmers of Rs. 10,000 for the recharge structures is not such a big constraint, nor is siltation, for which they suggest numerous innovative solutions. Managing dug well recharge locally is critical. Should it become mandatory for farmers to apply in groups of 10, as our sampled farmers suggest? Should the national programme be structured such that farmers are transferred the subsidy and construct the structures in April or May as they unanimously prefer? Should the policy instead be to promote local businesses around recharge, such as to harness the experience of well drillers, who also operate during the same summer months? More such tuning is needed over implementation of the dug well recharge programme to create demand from farmers, catalyze enterprises locally around recharge and establish monitoring programmes to measure the benefits from the first upcoming season in 2009 over lakhs of recharge structures.

Introduction

Individual farm based irrigation facilities has been one of the important reasons how irrigated area has increased in India for the past 3-4 decades. Whether the water for this irrigation comes from a reservoir or from the ground beneath, the farmer is at ease when he does not have to depend on a faraway control for irrigating his field. This facility however comes with its drawbacks. On one hand as it gives the farmer the luxury of adjusting his time towards his field activities, but it also puts the entire onus of assuring water availability to the farmer. This was fine in the initial years of groundwater development, but not so now. The boom, peak and bust of the groundwater revolution is now well known. The farmer, especially in the hard rock regions is desperate. After expectations that arose from rising incomes due the groundwater based irrigation, he now faces prospects of even more investment, greater risk and uncertain yield (NIH, 1999). This crisis has lead to distress and agony in the farmer community, who wish, but without hope, towards some strategy to salvage their irrigation infrastructure (Janakarajan, 1999).

Spreading canals all across this landscape is not a viable option given numerous physical and economic constraints. Debates often travels towards local options for water capture and on that front, numerous efforts have been initiated. But unlike the development of groundwater irrigation as an individual effort, these local efforts at water conservation have been primarily community efforts requiring collective action by a group of people. Hard it is to sustain such efforts, much energy often goes towards bringing about such community action. Is there any individual alternative by the farmer himself that can help in water conservation and sustaining the groundwater based irrigation?

The Central government has initiated the national programme for artificial recharge through dug wells in primarily hard rock districts of the country which also experience a high stage of groundwater exploitation. It is anticipated, over different phases, to utilize several million wells (aimed at 4.55 million) as recharge structures. Most of these wells are located on private land, therefore owned by farmers. The recharging of these private wells is being coordinated by state-wide implementation structure that differs from one state to the other. Currently, of early 2009, the two states that have gone on an overdrive for this program are Tamil Nadu and Gujarat. Other states are in earlier stages of organizing the implementation structure, identifying beneficiaries and going ahead with execution. By the monsoon of 2009, a few lakh wells would be covered by this program. That monsoon will provide us pointers for testing this idea and future potential.

The final end point and in fact the most crucial point in this entire structure is the well owning farmer(s). Once a recharge structure is in place attached to a farmer's well, utilizing this facility to perform recharge or enhancing and maintaining it in the future rests mainly with the farmer. What does the farmer think of such mode of doing recharge with his well? Does he feel there is a significant potential benefit to himself (and others) by such recharging? Does the farmer have other models and ideas to contribute?

Such questions should have preceded the implementation of the national programme itself? Currently the program is structured so that there is identification of farmers, transfer of funds and expectation that farmers would construct recharge structures. There is less thinking on how village level implementation should proceed and what support will be available to the farmer during and after construction of recharge structures.

In the past, success of such mass ventures by the farmer has proceeded only due to innovation by farmers themselves. The Saurashtra well recharge movement which later on provided base for community action on the check dam movement, succeeded because of a massive communication program by civil society groups that highlighted the need for water conservation amidst several years of drought. Farmers, charged by the idea went ahead and invested their own money and effort towards constructing recharge structures for their wells. Even today, much experience gained from those experiments in the mid 1990s is helping the farmer in Saurashtra to acquire higher yield of water in different ways (eg through horizontal bores etc).

If an idea such as having distributed recharge of dug wells across the country needs to succeed, it needs to start from the farmer's need, thinking and channeling it in this direction. For that, it is first essential to know what the farmer thinks about this idea and how much benefit he would accrue from it.

Worldwide, the need for enhancing recharge to groundwater started being felt on a large scale in the early 20^{th} century (Todd, 2004). Especially in the US, various experiments have been carried out continuously for many decades. These experiments have established different ways of doing recharge – basin spreading, stream channel, well recharging etc. California in the western US has been a pioneer in artificial recharging. The majority of recharging in California takes place through basin spreading in areas such as the Santa Clara aquifer. There are also well recharging experiments in the coastal areas to prevent ingress of saline water into fresh water aquifers. The source water for recharge is not just through rainfall runoff, but also through imported water supplied by canals as in the case of the Santa Clara aquifer. Interestingly in the context of India's groundwater recharge program, 2000 wells in a Basaltic aquifer have been used for recharge in southern Idaho Snake Plains aquifer where the fractured rock provides ample space for recharge. These experiments from the US have given some estimates on recharge rates after experience over several decades. Todd reports some of these recharge rates that generally hover around a few thousand cubic metres per day but with high variation from 200 cu m/day to 50,000 cu m/day.

In the Indian context, water harvesting and the concept of groundwater recharge is deep-rooted in cultural practices (Rosin, 1993). Today, many NGOs, private consultants and farmers have been trying out different types of well recharging efforts. The technologies are highly varied with much action on the ground. However, to have millions of farmers take up recharging on their dug wells, it requires a massive participation from the farmers themselves. This study has been designed to gauge at how farmers themselves perceive the value of their dug wells, if they see recharging as an effort worth enough and how they see the possible benefits from recharging. The purpose is to provide constructive inputs to current efforts in this direction.

The larger picture

Before going ahead into issues regarding well recharge, let us look at the large level potential of this idea. For this we utilize published data from the Central Groundwater Board (CGWB, 2004). Nationwide data on groundwater balance is available on a district level from this publication. Using this we have earlier categorized and added layers of similar district level data to create a large data set on groundwater, agricultural and related information (Krishnan et al, 2007). One of the layers added was the hydrogeology of the district. For our analysis here, we take only those districts which have more than

75% of their area in either Basaltic or in Crystalline Granitic formations. In our dataset, we have 112 such districts spread across mainly 11 states. The total annual groundwater recharge across these 112 districts is equal to 10141965 Ha.m and the total area of these districts is 87342454 Ha. This gives a recharge per unit area of 0.116 cu m/sq m. i.e. 116 mm of recharge per unit area. This is an average figure over this entire hard rock region of the country, therefore it will show variations depending on regional factors such as rainfall, infiltration properties etc. However, it gives us a rough number useful for discussion. Note that this recharge is subject to base flows and other natural flows, therefore the net available groundwater is a lesser quantity.

Table 1: Dug Well densities in Wells / Hectare groundwater irrigated area for different river basins

Cauvery	ERF_Bet_Go_Kr	ERF_Bet_Ma_Go	ERF_Bet_Pe_Ca	ERF_Sca	Ganga	Godavari
0.52	3.69	2.10	1.35	1.33	1.09	2.12

Krishna	Mahanadi	Mahi	Narmada	Pennar	Sabarmati	Subarnarekha	Tapi
0.73	3.52	1.79	0.88	0.36	1.19	2.41	1.14

Now consider a dug well of 20m depth with diameter of 8m i.e. a total volume of roughly 1000 cu m. If this well is used as a recharge well and fills to capacity once a year, then the volume of recharge is equal to 1000 cu m (We use representative dimensions due to lack of availability of national level data on well dimensions).

Further, we use data from the Agricultural census 2001 on number of dug wells. Totally, we obtained data from the same 112 hard rock districts on number of dug wells and net area irrigation by groundwater irrigation.

Table 1 shows the well densities calculated for each river basin only across the hard rock districts. The minimum well density is reported for the districts lying in Cauvery river basin, i.e. 0.52 dug wells/Ha of groundwater irrigated area and maximum of 3.69 dug wells/Ha for the east flowing river lying between Godavari and Krishna.

The total number of dug wells in these 112 districts is equal to 4,257,918 supposedly irrigating 5,420,434 Ha. No doubt, these data have errors and especially the data on net irrigated area (Dhawan, 1998). But we use these here due to lack of alternatives and to get rough figures. The average dug well density is, 4,257,918/5,420,434 = 0.78 wells/Ha over these 112 hard rock dominated districts.

The effective recharge per unit area of this dug well is therefore,

Recharge per unit area = Recharge from single well * well density i.e. 1000 cu m * 0.78 / 10,000 sq m = 0.078 m i.e. 78 mm i.e. 67% of the current recharge.

But what are the assumptions here? We are assuming that this 1000 cu m of recharge would have otherwise flown downstream without recharging into any downstream aquifer. We are assuming that the net base flows or natural flows from recharged water would be the same as before so that there is increase in water availability with this additional recharge. Also assumed here is that it is possible to recharge using dug wells during storm events, inspite of any water level increase (by a Hortonian or Dunne mechanism [1]; a hydrologic way of putting a common sense question: "How would water recharge from wells during rains when water level rises to so much close to the surface?"), a point which is countered by some observers especially in the hard rock areas (Kumar, 2008). Also assumed are the quality of water recharged through the dug well which if silt loaded could otherwise reduce infiltration through the well. In short, if all these assumptions are valid, we have a potentially powerful idea of using dug wells for recharging the aquifers and augmentation of current recharge by a significant amount. That is also, if, a lot of wells do such recharging.

Debates surrounding Dug well recharge

Discussions surrounding such a distributed mode of groundwater recharge through dug wells centre around some key issues:

1. Is there surplus runoff available for recharge through dug wells? Would this water recharge into the aquifer otherwise anyway downstream through ponds etc?
2. Considering that this recharge water also carries silt load (and agrochemicals) would the pore space close to the well get choked?
3. Would we ever have a mass number of recharge wells in place to achieve a significant increase in water availability?
4. During monsoon, when recharged water already saturates the low specific yield aquifers, is there more space at all?

Given such questions, we have designed this study to answer some of them:

1. What are current strategies being adopted by farmers for innovative management of dug wells in hard rock areas?

---

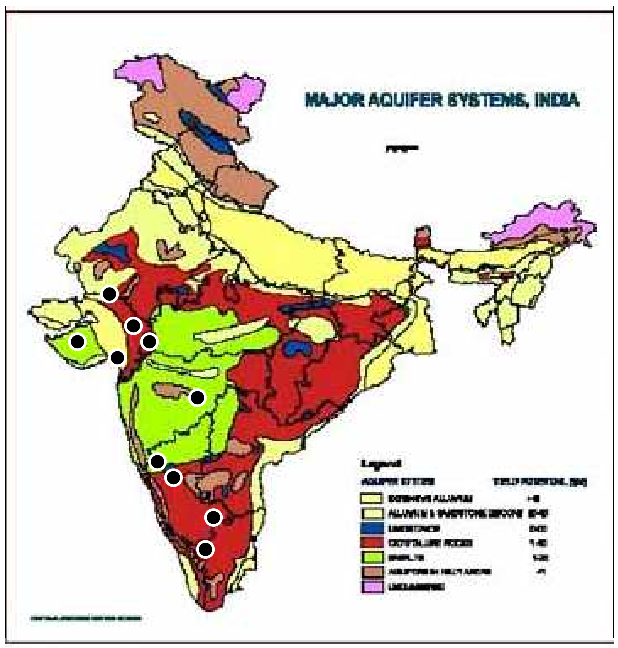
[1] There have been two main theories explaining surface runoff in catchments. The classical ***Hortonian*** *mechanism* propagated by Horton describes runoff as the excess water beyond the infiltration capacity of the soil (Horton, 1945). The infiltration capacity reduces with rainfall and after sufficient time, it is limited by the vertical hydraulic conductivity of the soil. In this conceptualization, if the rainfall rate is above this infiltration limit, runoff occurs. The classical theory of runoff considers this mechanism to be uniform over the landscape and the varying runoff patterns are explained by the variations in precipitation and in local soil conditions. However, such conditions were observed to be true mainly in semi-arid catchments with a deep water table. In field conditions, this theory failed to explain phenomenon such as pockets of runoff generation from local depressions and from hollows. An alternative mechanism was proposed by *Thomas Dunne* in the 70s in which runoff occurs when locally the water table rises to the surface (Dunne and Black, 1970). Such locations are generally depressions and topographic hollows that are recipients of subsurface flows. In such locations, the water table is locally at the surface and any precipitation has to flow as surface runoff. These two mechanisms: infiltration excess overland flow and the saturated overland flow together explain most types of surface runoff observed in small catchments that finally lead onto larger streams and rivers.

2. What potential further exists for innovative strategies such as recharge of dug wells? How do farmers perceive the potentials benefits and risks in such strategies?

3. How can dug well recharge programs be best implemented in hard rock areas of the country?

These studies were performed in 10 districts along with partners,
Gadag (G) and Haveri (H) districts of Karnataka; Anantapur (A) in AP; Jhabua (J) and Dewas (D) in MP; Rajkot (R) and Khambat (Anand), (K) in Gujarat; Yavatmal (Y) in Maharashtra; Dungarpur (D) in

Figure 1: Site locations overlaid on the hydrogeology map of India



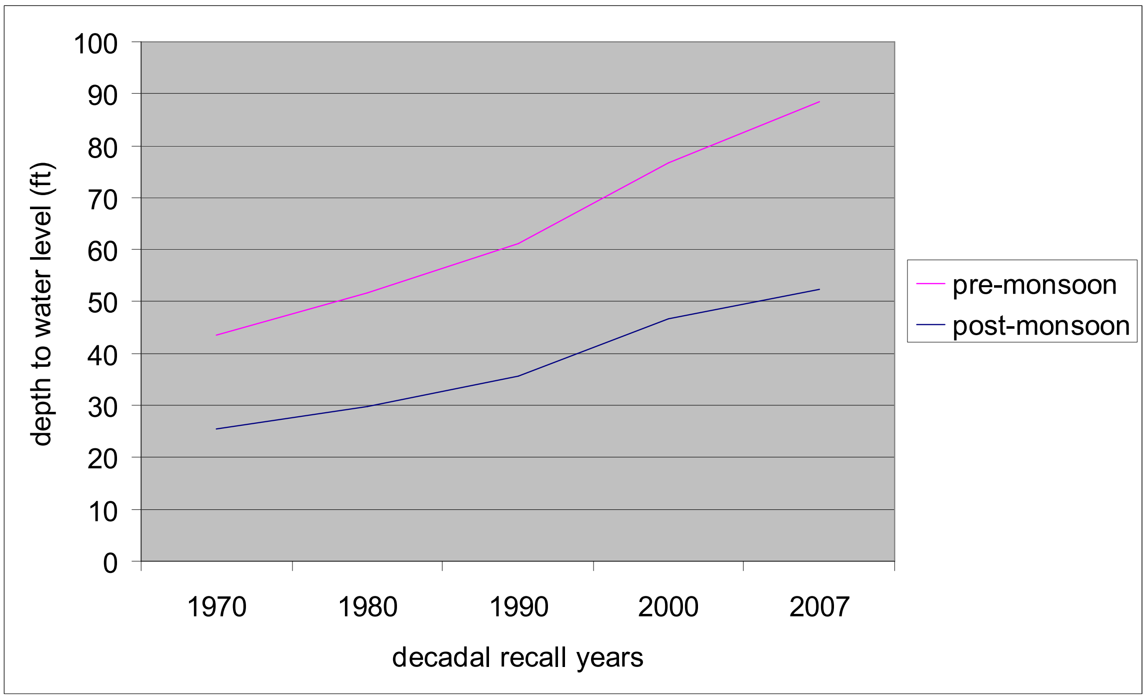
Rajasthan and Dharmapuri (D) in TN with 5 villages chosen at each site. Appendix 1 gives the names/organizations of the research partners for our study. A planning workshop was conducted in mid December, 2008 to discuss issues and arrive at researchable points. The finalized methodology was designed and field work started by end of December till end of January, 2009.

Base groundwater picture of study areas

The study areas are all located in either Basalt or Crystalline rock areas of the country except for Khambat which is a saline affected coastal alluvium area where the dug well recharge programme of the govt is being implemented (Figure 1).

Figure 2 shows the trend in average pre and post monsoon depth to water levels over the study sites. These figures have been obtained as recollected knowledge during group discussion in each of the 5 study villages of each site. From 1970 till date there has been a steady perceived drop in water levels by roughly 4-5 ft per decade. Along with this, as reported by the sampled farmers, number of dug wells increased but were overtaken by bore wells in the past 2 decades.

Figure 2: Average pre and post monsoon depth to water table in dug wells as reported by group discussion in the site studies, from 1970, 1980, 1990, 2000 and 2007 seasons



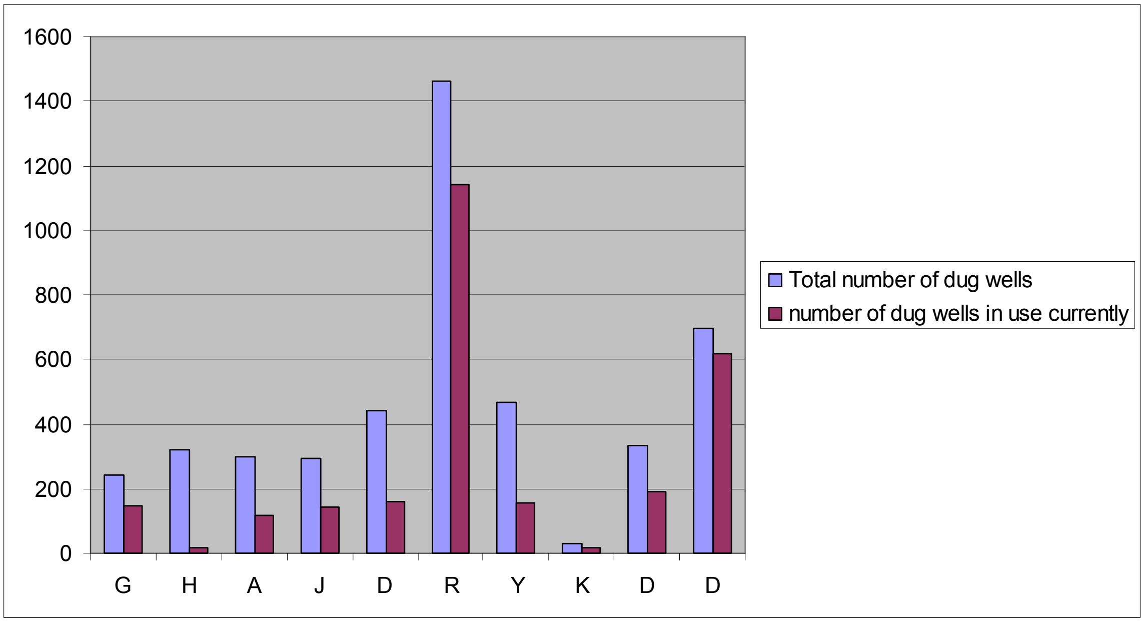
Roughly 42% of dug wells and 48% of bore wells are abandoned. This reflects the massive investment by farmers which has now gone waste because of fall in water levels and greater competition for water from new irrigation wells in the study villages.

Well volume and perception on recharge potential

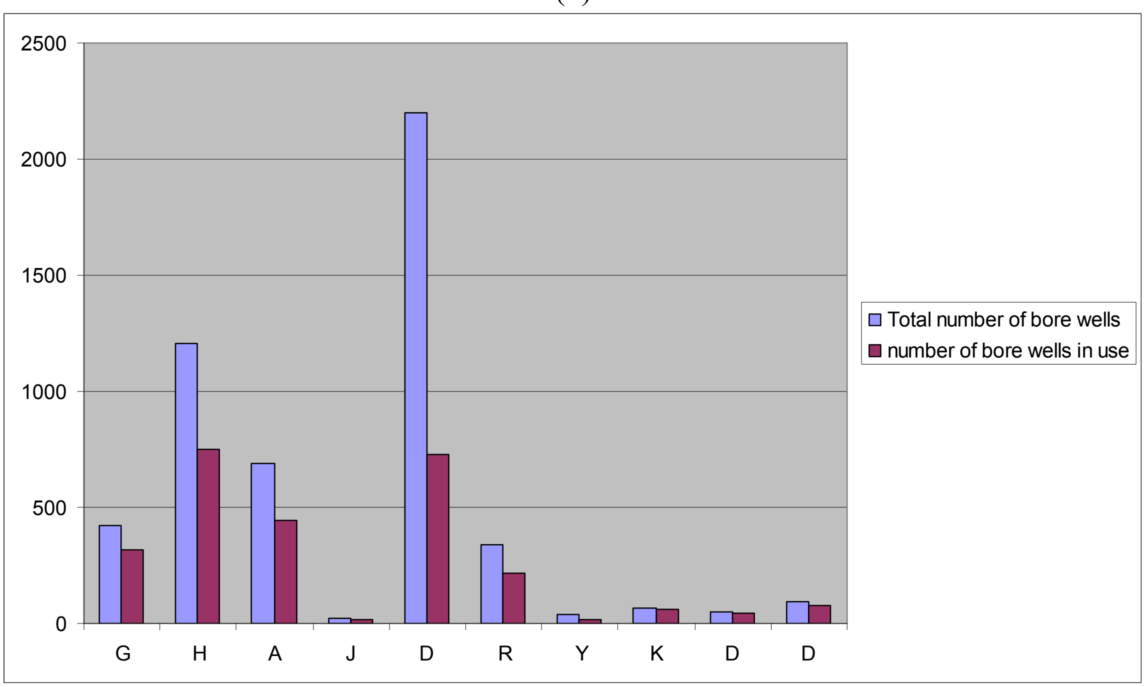
Data on well dimensions is lacking from any of the surveys conducted by different agencies. Well storage volume is important in determining the total capacity of recharge possible from wells. However, this alone is not sufficient. The rate of recharge, especially during storm events is crucial. Studies indicate that in some hard rock areas, the water level shows a sudden rise up to the ground level during rainfall events. This might be due to Dunne type of runoff mechanism prevailing in such watersheds. In such cases, the rate of infiltration from wells would drop down rapidly and recharge would not be possible till the water level drops down again. Here, we utilize the farmer's own observation of drainage time from their wells to calculate the average recharge rate possible from their wells.

Figure 3: Currently existing and in-use, (a) dug wells and (b) bore wells, for different study sites

(a)



(b)



We sampled a total of 767 wells whose average dimensions come out as
Average depth = 41 ft, average diameter = 12.6 ft. There is variation in well size from site to site, with a maximum of 60 ft diameter well from Haveri district in north Karnataka.

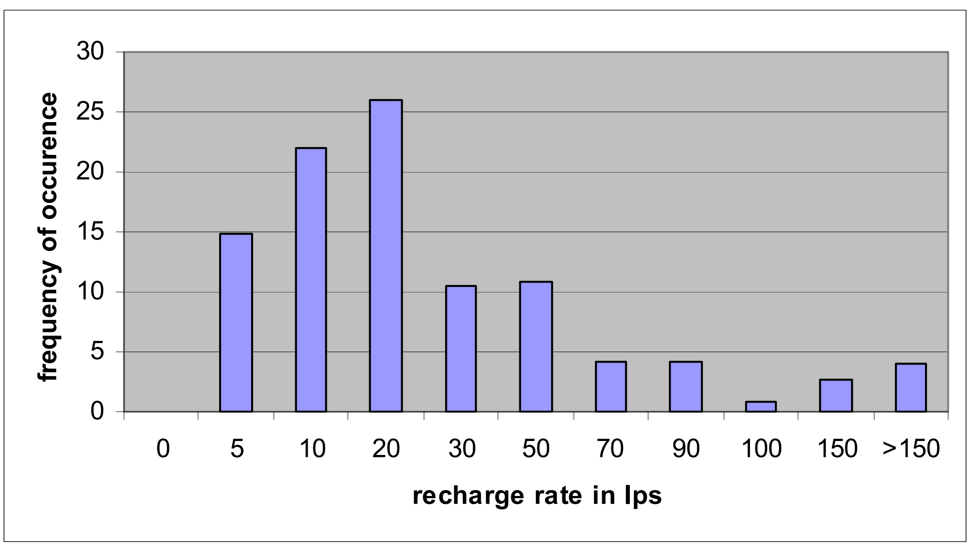
Table 2 shows the well volumes in cu. m. calculated from our field studies in 8 sites. The average well volume from 767 wells is 467 cu m. Also collected is the time it takes to drain out the well completely which is an average of 30 hours. The drainage or recharge rate shown in Table 3 are calculated as Well volume/Time of drainage.

Table 2: Well volumes in cubic metres calculated from different site studies

Gadag	Haveri	Anantapur	Jhabua	Devas	Rajkot	Yavatmal	Khambat	Dungarpur	Dharmapuri
327	820	1067	215	507	192	234	248	327	440

The distribution of reported recharge rates from sampled wells in shown in Figure 4. The reported recharge rates are highly skewed. Since the number is not a typical Cartesian quantity and in fact, shows a tendency towards log-normal distribution, we take the exp(average(log(Recharge Rate))) instead of the more commonly used simple average that exaggerates the extreme high values (Tarantola, 2005). We get this transformed average value as 3.22 lps. The minimum average of 2.6 l/s was reported from Anantapur and maximum average of 6.05 l/s was reported from Dewas.

Figure 4: Cumulative frequency of recharge rate in lps from sampled wells



Athavale reports a recharge rate of 225 cu/day (2.6 lps) from a recharge well in central Mehsana in 1983, 192 cu m/day (2.22 lps) and 2600 cu m /day (30 lps) from injection methods in coastal Saurashtra, 45 lps from a pressure injection test by Gujarat water resources department near Ahmedabad city in 1974, 43.3 lps from an injection experiment using canal water in Haryana by central groundwater board. All these experiments were conducted in primarily alluvial aquifers. For hard rock aquifers, an NGRI experiment in Anantapur showed a recharge rate of 40 lpm.

As compared to these number, Todd reports recharge rates varying from 2.3 lps to 570 lps. Especially to be noted for hard rock areas is that the presence of veins or fractures near the recharge well that can carry of the recharge water into a deeper aquifer can impact the recharge rate to a great extent. The distribution of values of recharge rates will show high skewness across wells.

Table 3: Well recharge rates in litres per second reported from site studies

Gadag	Haveri	Anantapur	Jhabua	Devas	Rajkot	Yavatmal	Khambat	Dungarpur	Dharmapuri
3.46	3.1	2.62	3.4	6.05	2.56	1.15	1.63	2.71	4.54

Next we also collect data on the number of times farmers perceive their well to fill up during the monsoon if recharged. This is a purely estimated quantity since farmers have not yet experienced such recharge.

Table 4: Expected number of times well would drain out with recharged water annually

Gadag	Haveri	Anantapur	Jhabua	Devas	Rajkot	Yavatmal	Khambat	Dungarpur	Dharmapuri
0.63	0.715	7.78	3.58	2.5	2.89	1.61	0.96	3.1	2.8

The average number of times of recharge comes out as 2.83. Using the well volumes and the number of expected times of recharge, we compute the expected volume of recharge as Well volume * expected number of times of recharge.

Table 5: Expected volume of recharge from dug wells in cubic metres annually

Gadag	Haveri	Anantapur	Jhabua	Devas	Rajkot	Yavatmal	Khambat	Dungarpur	Dharmapuri
198.27	561.75	8578	876.73	1361.93	559.47	363.37	233.403	1030.18	1112.17

The average well recharge volumes comes out as 1591.62 cu m. Using this average recharge capacity of the dug well in our initial calculation on potential of such recharge,

1591.62 cu m * 0.78 / 10,000 sq m = 0.124 m i.e 124 mm i.e. 7% more than the average current recharge calculated previously as 116 mm. This is a really significant number, i.e. to say that the average recharge over groundwater irrigated hard rock areas can be increased by over 100%, but as mentioned in the earlier parts of the paper, we can make this statement over several assumptions.

For the 112 districts, if there are 4.25 million wells recharged, then we will have,

Total recharge = 4.25 million * 1000 cu m
i.e. 4.25 billion cu m of recharge or 4.25 BCM,

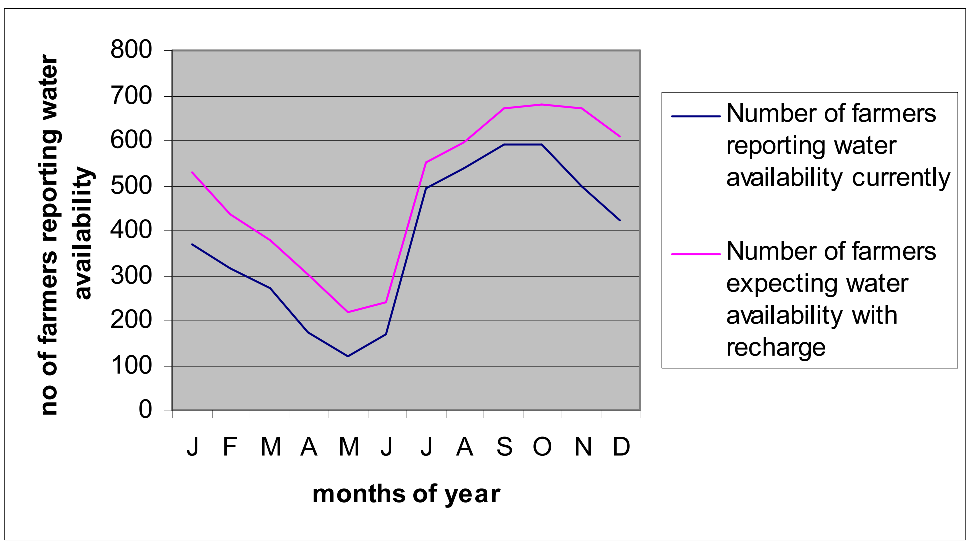
A total of 101 BCM of recharge is happening annually over these 112 districts (from CGWB, 2004), so a net increase of around 4% over this total groundwater recharge.

Otherwise taking only the groundwater irrigated areas in these districts, we have a total of 9.99 BCM of recharge happening now. So we have a net increase of 42% over this potentially.

Next,
Figure 5 shows the number of farmers in our sample of 767 who perceive water to be available in their well in a particular month with and without recharge. On an average, there is a 36% increase in the number of wells expected to have increased water availability with recharge. This increase is more in the dry seasons than in the wet seasons. It reflects more the need that people wish with recharge, and less what would actually happen.

What is sure from these expected potential benefits of recharge that there is a demand from farmers for such an option. The numbers reported here are perceptions and results of a survey, therefore not to be taken as literal figures. However, in face of lack of such information, this is the best we have, at the least indicating the potential farmers hope with dug well recharging.

Figure 5: Number of farmers reporting water availability in their dug wells currently and with recharge



The question now is what are the constraints to going ahead for recharge? Why are farmers not implementing recharge structures by themselves when they come to know about it? As compared to costs of the well itself of enhancements to the well such as deepening and boring, the cost of constructing a recharge structure are not too high. If the farmer feels that this would be beneficial, they would have gone ahead by themselves. So, …, what prevents them from doing so?

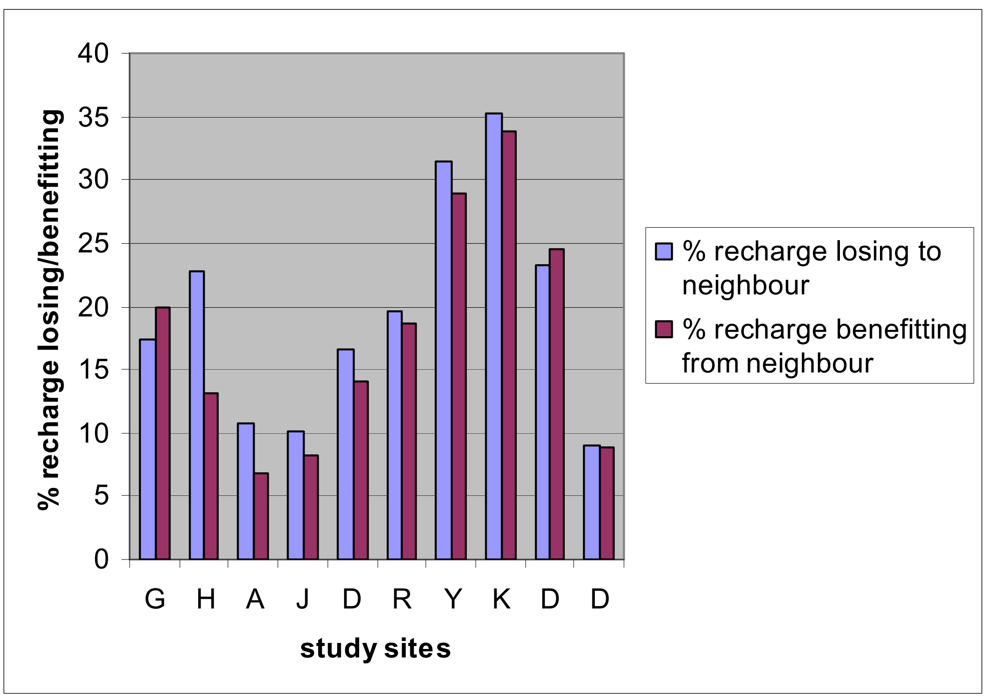
Constraints to implementing dug well recharging by farmers

One constraint to a farmer adopting dug well recharge is his perception about whether the recharged water would be available to him for pumping. Naturally, if there are conduits for water to flow across to other nearby wells, he would be disinclined to recharge. This was evident from our survey. Moreover, if there are deeper wells nearby, one would be further lesser inclined to recharge.

Our sample of 767 farmers feel on an average that their water yield reduced by 16% on an average and their well water level goes down by 4ft when their neighbour pumps from his well. Therefore, there is always this perception of sharing a common aquifer; this carries over to recharging also.

Except for one, all sites see a greater expectation of loss of water to neighbour rather than gain from neighbours by recharging. In general, there is no reason to expect this over a reasonably large data set, but here we see a common trend (except for the first site) of greater expectation of loss. This is a sure impediment to recharge. Unless the neighbour also recharges, the present farmer would not take much effort towards recharging.

Figure 6: Expected percentage loss of recharged water to neighbour or benefit from neighbour across different sites

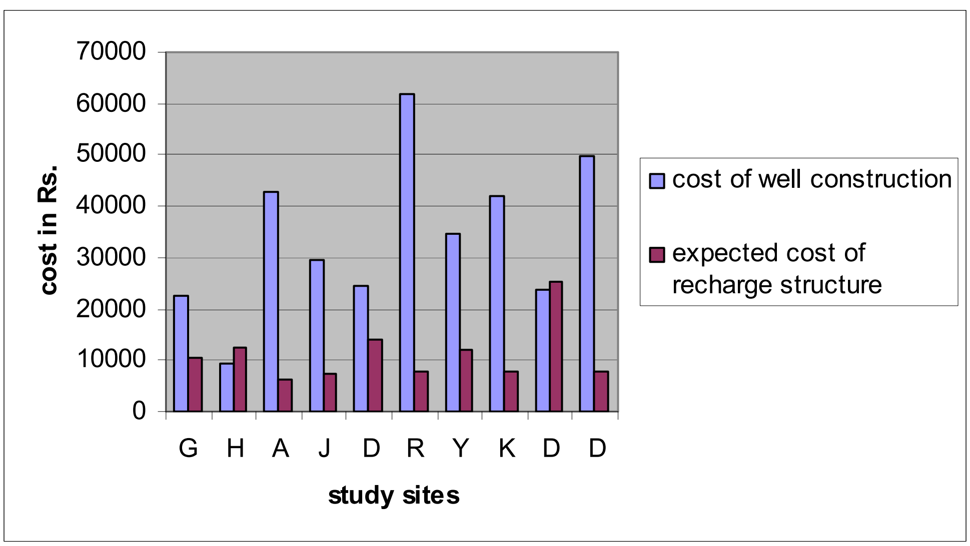


There is wide variation over the well construction and estimated costs of well recharge structure which averages to around Rs 10000/- i.e. Rs. 6.28/cu m of annual recharge (from previous calculation of average recharge = 1591.62 cu m/well). That itself is a significant investment since the returns from recharging are not as directly evident as that from say, well deepening. There is always the risk that the water that is being recharged would not be available to oneself. Further, around 60% of the sampled farmers report that the water collection point in or near their farm lies above (in terms of elevation) to their well. This means that either they use a field channel or more surely, make arrangement for underground boring to transmit water to their well. Such types of underground boring to transmit water to the well for recharging have been in vogue in parts of Saurashtra. But that involves a further investment of say, Rs 5,000, or more. Around 45% of the sampled farmers report that they would require investing on such type of underground boring and pipes.

An unexpected problem reported by farmers is that of possible caving in of the well, especially in unconsolidated formations. Some farmers feel that since the recharged water falls to the bottom of the well from a height, it could deepen the sides of the well foundation and result in the well caving in. In this context, care has to be taken to let the water flow along the sides of the well so that it does not create an impact at the bottom.

Siltation is reported as a potential problem by 67% of sampled farmers. But they also mention numerous innovative ways to counter siltation eg. using mosquito nets, planting thorny shrubs to capture waste, small bunding to arrest direct transport of silt, etc. Farmers seem confident that siltation, though a problem, can be countered.

Figure 7: Reported average costs of well construction and average estimated local costs of recharge structure



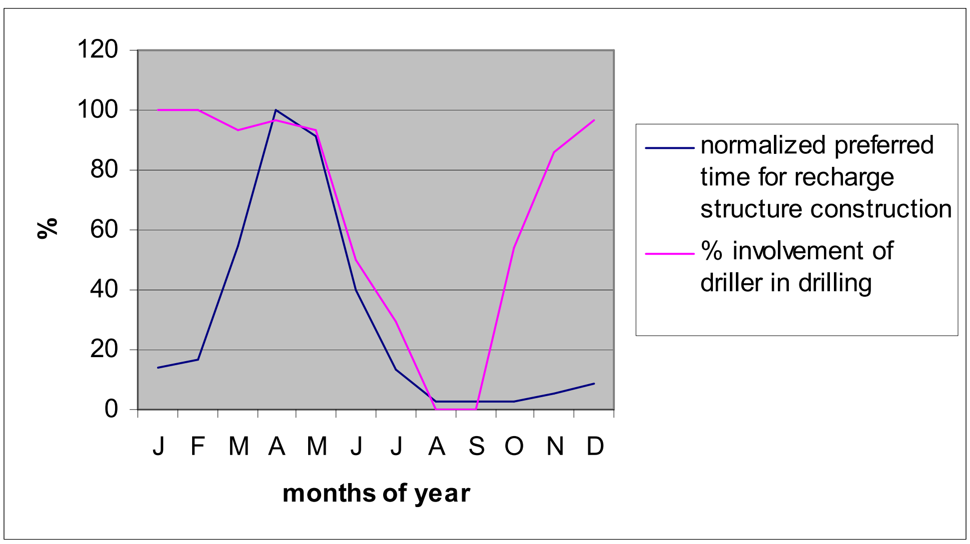
All these are reflected in the choice chosen by farmers when asked what they would do with Rs. 4,000. Around 45% of farmers chose recharging, while 43% chose to deepen their wells. Well deepening is psychologically an accepted proposition for an individual private well owner to invest on for increasing well yield. On an average, farmers in our sample have spent Rs. 16,200 for well deepening.

Here some points of comparison can be made between recharging and well deepening as investments for increasing well yield. The more the farmer invests on a well, his risk is increasing. Each additional investment is a sort of "protection" for all earlier investments made on the well. There is always a chance that with one additional deepening, the well yield suddenly increases significantly. The farmer is playing a risky game, and with each additional investment, the game gets riskier. Additionally, the more number of farmers invest in deepening, the benefit to individual farmer reduces.

This logic gets reversed in the case of well recharging. If farmers recharge instead of deepen, there is increasing individual benefit when more farmers recharge. One gains when others invest too. Up to a limit, there is decrease in risk with each additional investment.

Therefore, the economics of well deepening and recharging go contrary to each other. Somewhere there is a balance, which is currently tilted towards well deepening. The space is therefore set for more recharging.

Figure 8: Comparing preferred time for constructing recharge structures and times of well construction



Management of recharge structures

Looking as recharging as one means of resuscitating dry or semi-dry dug wells, it seems that the current mode of implementation of the National programme on artificial dug well recharge would possibly face some constraints. Expecting individual farmers to construct recharge structures with a subsidy amount of Rs 2,000 or Rs 4,000 means that there is sufficient interest in the farmer to begin with. Enabling recharge is not just about constructing the structure, but also making flood water pass through it, cleaning the structure of silt and other waste that collects near it and making repairs when required.

All these need a proactive farmer who sees a benefit, common if not personal, in recharging.

As opposed to just 20-30% of benefit if a neighbouring well recharges, almost all farmers agree that if they as well as their neighbours recharge there would be benefit to both of them. Further, 93% of sampled farmers felt that it will be good if farmers apply for recharging as a group, even though they implement it individually on their wells. They reported that an average of 10 farmers should apply together for recharging. The number 10 probably comes form their intuition of finding a balance between the hassle of arranging a group application and the worthiness of larger number of farmers recharging together.

Farmers are also accepting to alternative ideas for recharge. Gujarat farmers in our sample were already practicing recharging of dug wells using canal water. This was very much so in the Mahi tail command area of Khambat where the irrigation department has innovated a unique mode of water distribution through underground sumps. The canal water is used by farmers for recharging their dug wells, a practice being followed for at least a decade. On average, farmers reported that they could spend up to Rs. 5000 towards pipes and other material, if there was a scheme at recharging their wells through canal water. However, such a scheme is not possible at many places since such canal water is not available everywhere. Mention must be made here of a similar mechanism of water distribution being followed currently in the Sardar Sarovar command area of Gujarat where farmers have been spending as much as Rs. 1000-5000 per hectare towards pipes and pumps for accessing water from the branch and minor canals.

The timing of constructing recharge structures is also critical. The structure needs to be constructed before monsoon, before a sufficient period so that there is time for the concrete to cure and stabilize. April was reported as the best month for constructing recharge structures and an average of 12 days was reported to construct the structure. April is also a time when well construction is at its peak. This brings us to an interesting point to leverage as linking between well construction and well recharge. Figure 8 compares the relative yearly schedules of well drillers with the reported preference of farmers for constructing recharge structures. The graph points to April as a time when drillers are engaged, in well construction, so why not involve them in constructing recharge structures too.

We interviewed 30 drillers across the sites about their views on recharging as an option for dug wells. Interestingly, drillers too report an average of around Rs 10,000 for constructing the recharge structures. They prefer May slightly over April as the best time for constructing the structures, and suggest a higher number, 22, on average, number of farmers to recharge together for getting greater benefit, perhaps discounting the hassles in group applications by farmers. However 2/3 drillers showed interesting to participate not only in taking up constructing recharge structures as a business, but also play a role in monitoring them and seeing the impact with monsoon. They report on average to charge Rs. 8600 for constructing a recharge structure and also showed interest in getting trained on these aspects. Well drillers, especially in the hard rock areas show high sense of local knowledge in their areas as shown by previous studies (Krishnan, 2008), so why not utilize their expertise towards a natural extension of their profession?

What is the best way to do recharge? How much common benefit will it result in? What is the best way to implement the programme at the village level? These questions need to be asked more to check the worth of this idea. If it works, farmers will pay and take it up by themselves. Probably the monsoon of 2009 will answer some of these questions.

Thoughts and Ideas

Whether localized governance of groundwater in hard rock areas is to be pursued is probably not a question today. How to do it: through pricing (water, energy), legal regulation, community institutions – these are the important questions. Whatever be the framework as a combination of these ideas, water supply augmentation and demand management are both to be taken care of, directly through regulation or through indirect instruments such as pricing. Dug well recharge offers one option at water supply augmentation locally, an option that involves the ultimate stakeholder – the farmer – quite deeply. The farmer, through this mode of supply augmentation by his own efforts, would perhaps also get attuned to thinking about demand management. Till now, groundwater was always sourced from recharge naturally through rainfall or ponds, or from canals. But once the farmer gets involved in water supply, it could change his thinking forever. In that vein, dug well recharge should be seen within a broader framework of how to address groundwater governance locally and not in isolation.

Dug well recharge also could potentially become an instrument through which access and record of the millions of dug wells can be sequenced and maintained in a database. It could be a means of information exchange, both from farmer and to the farmer. Crucial hydrogeological and hydraulic data can be passed by the farmer, whereas, scientific and policy information can be passed down to the farmer. If this idea is utilized towards these objectives and strengthened through appropriate institutions at different levels, then there is much that can be gained through this programme. Dug well recharge can be a backbone of a mass scientific experimentation involving millions of farmers and giving an opportunity to test many of the new ICT innovations. The Tamil Nadu recharge programme is attempting a bit in this direction by maintaining electronic records and hoping to get constant feedback from farmers.

However, in this discussion about dug well recharge, we should not forget the other competitive ideas which are also being tried today. Group owned wells in tandem with recharge ponds, bore well recharge, small to large surface water harvesting structures, underground dykes – the list is endless, as many as the different groups that have been experimenting these ideas. As said earlier, instead of losing ourselves into just one of these possibilities, we need to be thinking on the broader context of how they all fit together, what is relevant where, and how will they enable supply and demand management of groundwater locally.

A last note should be made of uncertainty – both epistemological and experimental; i.e. from methodological as well as data. Especially, within this study when we sample just few hundred wells out of millions, there is surely a question of sampling and representativeness of the sample. This, we try to counter slightly, but certainly not in entirety, by taking two data sets, one over a national level (that is close to exhaustive, but error prone), and another of our own sampled data that has better control of data errors. We have attempted to utilize both these data sets in order to support the analysis in this paper.

The next question on uncertainty and perhaps more important is on methodology. Looking at the physical context, a unit of aquifer of watershed and a time scale observation of few seasons is essential to make any statement of reasonable accuracy. Especially in hard rock areas there have been research groups which have worked on a single 1 km^2 plot of fractured rock for decades in arid Arizona to finally conclude unsurpassable uncertainty. Here, we have relied on localized farmer and well driller knowledge that is gathered through years of observation, but without any scientific training. As such, it is subject to opinions, perceptions and biases as opposed to more objective, repeatable and potentially error minimizable nature of scientific data. Neither is the substitute for the other, only complementary. We have therefore, tried to refer to scientific studies and utilize them as much as possible. Any additions on that front would be valuable.

References

Athavale, R. N., 2003, Water harvesting and sustainable supply in India, CEE Ahmedabad, Rawat Publications

CGWB, 2004, Dynamic Groundwater Resources of India

Dhawan, B. D., 1990, How reliable are groundwater estimates?, Economic and Political Weekly, 19:1073-1078 (May)

Dunne, T. and R. D. Black, 1970, An experimental investigation of runoff production in permeable soils, Water Resources Research, 6, 478-490

Horton, R. E., 1945, Erosional development of streams and their drainage basins; Hydrophysical approach to quantitative morphology, Bulletin of the Geological Society of America 56, 275-370

Janakarajan, S., 1999, Conflicts Over the Invisible Resource: Is there a Way Out?' in Moench, M., Elizabeth Caspari and Ajay Dixit (eds.) Rethinking the Mosaic: Investigations into Local Water Management, published by NWCF and ISET (USA)

NIH, 1999, Hydrological Problems of Hard rock region

Krishnan S., Raychoudhary T. , Purohit C. and. A. Patel, 2007, Environmental impacts of groundwater intensification in India, in IWMI-NRLP Studies Report

Krishnan S., 2008, Duel between Duals: Basaltic Hydrogeology of a village in hard rock Saurashtra, in Proceedings of Annual Partner's Meet, IWMI-Tata Water Policy Programme, Hyderabad

Krishnan S., Islam A., Machiwal D., Sena D. R., and K. Villholth, 2008, Living Wisdom: using local well driller knowledge to construct digital databases in Indo-Gangetic basin , Groundwater Governance in Asia Research Studies ,in Special Edition of Hydrogeology Journal

Kumar D., Patel A., Ravindranath R. and O. P. Singh, 2008, Chasing a Mirage: Water Harvesting and Artificial Recharge 61 in Naturally Water-Scarce Regions, Volume 43, Number 35, August 30 - September 05, 2008

Mohandas M. and N. Gupta, 2009, Evolving effective implementation protocol of government of India's dug well recharge programme, Management Trainee Segment report, IRMA

Rosin, T., (1993), The tradition of groundwater irrigation in northwestern India. *Human Ecology* 21(1):51-86.

Tarantola A., 2005, Inverse problem theory and model parameter estimation, SIAM Publications

Shah T., 2008, India's Master Plan for Groundwater Recharge: An Assessment and Some 41 Suggestions for Revision, EPW, Volume 43, Number 51, December 20-26, 2008, pp. 41-49

Todd, 2004, Groundwater Hydrology, Wiley

Appendix 1: Research partners for study

Site	Research Partner
Gadag	Navchetana Rural Dev Society
Haveri	SCOPE
Anantapur	Hirudia Raj
Jhabua	GATE
Dewas	GATE
Rajkot	SAVARAJ
Yavatmal	Vivek Kher
Khambat	INREM, Upen Mahida
Dungarpur	PEDO
Dharmapuri	DHVANI