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COMMUNITY RESPONSE TO AQUIFER DEVELOPMENT: DISTINCT PATTERNS IN INDIA'S ALLUVIAL AND HARD ROCK AQUIFER AREAS†

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ABSTRACT

The boom that India has experienced in groundwater irrigation is only weakly related to the availability of groundwater resources, long-term recharge rates and even availability of surface canal infrastructure. Dependence on groundwater has increased in rich alluvial aquifers with ample storage as well as in poor hard rock aquifers with limited storage. The socio-economic and environmental impacts of the over-exploitation of groundwater are also equally pervasive. This paper shows that some, though not all, responses to groundwater over-development from farming communities are different in 'thick' alluvial aquifer areas from 'thin' hard rock aquifer areas. In the former, users fail to comprehend their interdependence, and consequently, to behave like an 'aquifer community' sharing a limited resource. As individual users, they engage in competitive deepening of boreholes to chase declining water levels. In arid alluvial areas, there is no sign of groundwater users trying either supply- or demand-side initiatives to make groundwater use sustainable. In contrast, many hard rock aquifer areas in India are seeing spontaneous initiatives from farmers, communities, NGOs and other players to cope with or counter aquifer depletion, mostly by individual or group efforts to increase groundwater recharge, but less so by making and enforcing rules to limit withdrawals. Copyright © 2012 John Wiley & Sons, Ltd.

KEY WORDS: community response; India; groundwater; hard rock; alluvial

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RÉSUMÉ

Le boom que l'Inde a connu dans l'irrigation à partir des eaux souterraines n'est que faiblement lié à la disponibilité de ces ressources, ni à son taux de recharge à long terme, ni même à la présence d'infrastructure de canaux de surface. La dépendance aux eaux souterraines a augmenté aussi bien dans les régions d'aquifères alluviaux à forte capacité de stockage que dans celles d'aquifères de socle de faible capacité. Dans les deux cas, les impacts socio-économiques et environnementaux de la surexploitation des eaux souterraines sont omniprésents. Ce papier montre que les réponses à la surexploitation des nappes par les communautés d'agriculteurs peuvent différer selon que les aquifères sont alluviaux ou de socle. Dans le premier cas, les usagers ne parviennent généralement pas concevoir leur interdépendance, et par conséquent, à se comporter comme une « communauté d'aquifère » partageant une ressource limitée. En tant qu'usagers individuels, ils s'engagent dans une course à l'approfondissement des forages à la recherche d'une eau toujours plus profonde. Dans les zones alluviales arides, aucun signe d'une recherche de solutions alternatives pour améliorer la durabilité de l'usage de la ressource n'est perceptible, ni du coté de la demande ni du coté de l'offre. En revanche, de nombreuses régions d'Inde de type aquifères de socle connaissent des initiatives spontanées d'agriculteurs, de communautés, d'ONG et d'autres acteurs pour faire face ou lutter contre l'épuisement des aquifères. La plupart du temps, il s'agit d'efforts individuels ou collectifs pour augmenter la recharge des nappes souterraines, moins souvent pour élaborer et mettre en œuvre des règles pour limiter les prélèvements. Copyright © 2011 John Wiley & Sons, Ltd.

MOTS CLÉS: action collective; Inde; eaux souterraines; aquifères de socle; zones alluviales

INTRODUCTION

For millennia, India has been an irrigation civilization. However, the technology and organization of irrigation have

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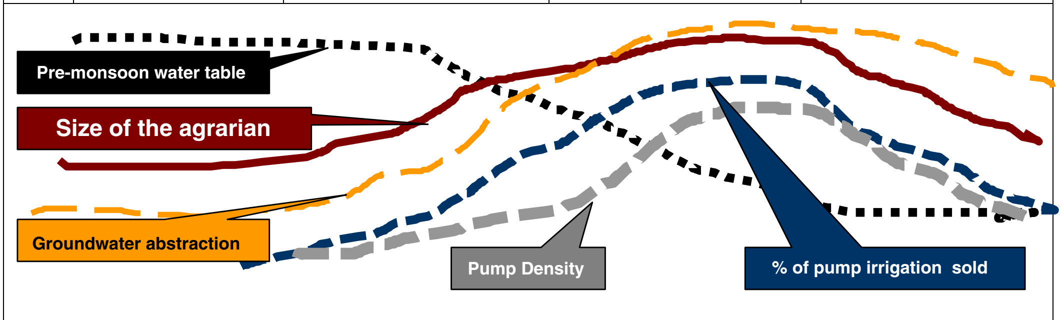
† Réponse communautaire au prélèvement dans les aquifères en Inde: des schémas distincts si l'aquifère est dans une zone alluviale ou de roches dures.

undergone massive changes over the millennia. We can divide India's irrigation history over three overlapping phases. The first (until the early 1800 s) was marked by an era of *adaptive irrigation* when farming communities and local overlords were key irrigation players. Human settlement and cultivated areas were determined by hydrological factors. Diverting and managing monsoon flood waters to support riverine agriculture was the dominant mode in the north and west. Using monsoon floodwaters to fill up countless small reservoirs was the standard procedure in the east as well as in the hard-rock parts of peninsular India where seepage losses from water storages were insignificant (Bagchi, 1995; Agarwal and Narain, 1997; Habib, 1999). This was followed by Phase II, *the era of canal construction*. Begun by the British around 1810, this tradition continues today. In constructing ambitious canal irrigation projects, the colonial rulers combined the 'interests of charity and the interests of commerce' (Whitcombe, 2005). The welfare state of independent India continued building large irrigation systems, more for improving food security and agrarian livelihoods than for rent extraction. However, the organizational model remained the same: the state and centralized irrigation bureaucracies replaced village communities and local landlords as key players in the new regime. Civil engineering domination of water planning, construction and management continued even after India became independent and remains predominant today. This tradition left India (and Pakistan) with some of the world's largest gravity flow irrigation systems, complete with a highly centralized, bureaucratic irrigation management regime.

This irrigation strategy, however, created pockets of agrarian prosperity in canal commands, which even as recently as 2000 encompassed no more than 15% of India's farming areas (Shah, 2009). However, India experienced an explosion in agricultural population since 1950; and the land:man ratio declined from over 0.4 ha per person in 1900 to less than 0.1 ha per person in 2000 (Sikka and Gichuki, 2006). Need was felt by peasants around the country to secure means of irrigation that could permit intensification and diversification of land use; small and marginal farmers, under greater pressure to intensify and diversify, increased their groundwater irrigated area to a greater extent than medium and large farmers did (Shah, 2009). Geographically too, districts with higher demographic pressure on farm lands experienced more rapid growth in tubewell irrigated areas compared to sparsely populated districts, *ceteris paribus* (ibid). This powerful demand-side factor was matched by a host of supply-side factors including a government policy that strongly supported and heavily subsidized private groundwater development. The availability of small mechanical pumps and boring rigs provided a technological breakthrough. But even more powerful was an enduring policy of supplying free or highly subsidized electricity to farmers, which made groundwater irrigation extremely attractive. Free or subsidized power created booming groundwater markets (Shah, 1993) and an explosive increase in demand for electric tubewells. From around 1970, this combination of circumstances catalysed a groundwater revolution all over South Asia ushering in a new era of atomistic irrigation driven by population pressure on farm lands (Bhaduri *et al*., 2011). In India, the number of irrigation wells equipped with diesel or electric pumps increased from some 150,000 in 1950 to nearly 19 million by 2000 (Government of India, 2005). In 1960, India was a relatively minor user of groundwater in agriculture compared to countries like the United States and Spain; by 2000, the country had emerged as the global champion in groundwater irrigation, pumping around 220–230 billion $m^3 yr^{-1}$, over twice the amount the US did, as the chart in Figure 1 shows (Shah *et al*., 2007). The groundwater revolution, and the complex task of governing it, has begun to change water discourse in India. This new phase has witnessed the decline of the state and centralized irrigation bureaucracies as the builder and manager of the irrigation economy; instead millions of small-scale private *atomistic* irrigators have taken charge of the irrigation economy (Shah, 2009).

The ways of this atomistic irrigation economy have been different from the earlier phases. The canal construction phase was supply-driven; command areas came up wherever sites were found suitable for reservoirs. In contrast, atomistic irrigation has been wholly demand-driven; desperate smallholders yearned for captive wells regardless of groundwater availability conditions. Technical and institutional innovation in drilling, digging and finding water-bearing pockets was driven by this desperation (Krishnan, 2008). In earlier phase of canal construction, water resources were extensively studied, modelled and mapped before appropriate plans for their development were prepared by scientifically trained and qualified professionals. Atomistic irrigation developed in waves, mostly in trial-and-error mode, in areas that promised abundant resources as well as areas that were doubtful. It is not that the scientific information was not there. India's Central Ground Water Board (CGWB) was established during the mid-1940s precisely to monitor groundwater levels. The CGWB had found long ago that the Indo-Gangetic plains were ideal for large-scale development of groundwater irrigation and that most hard rock areas of peninsular India were not. Yet, farmers all over the country began investing massively in groundwater irrigation in the 1970s, when population pressure on farm lands peaked, as did the demand for the intensification of agriculture, and all manner of government support began to be available. Concerns were expressed about this chaotic expansion in groundwater structures, its sustainability and environmental impacts; and some governments and financing agencies did try to formulate rules to control

	Stage 1	Stage 2	Stage 3	Stage 4
Stages	The rise of Green Revolution and Tubewell Technologies	Groundwater-based Agrarian Boom	Early Symptoms Groundwater Over-draft	Decline of the Groundwater Socio-ecology with immiserising impacts.



	Stage 1	Stage 2	Stage 3	Stage 4
Examples	North Bengal and North Bihar, Nepal Terai, Orissa	Eastern Uttar Pradesh Western Godavari Central and South Gujarat	Haryana, Punjab, Western Uttar Pradesh, Coimbatore and Madurai, Tamilnadu	North Gujarat, Coastal Tamilnadu, Coastal Saurashtra, South West Bengal
Characteristics	Subsistence agriculture; Protective Irrigation in Traditional crops; Concentrated rural poverty; Traditional water lifting devices using human and animal power	Skewed ownership of tubewells; access to pump irrigation prized; rise of primitive pump irrigation `exchange' institutions. Decline of traditional water lifting technologies; Rapid growth in agrarian income and employment	Crop diversification; permanent decline in water tables. The groundwater-based `bubble economy' continues booming; But tensions between economy and ecology surface as pumping costs soar and water market become oppressive; Private and social costs of ground-water use part ways.	The `bubble' bursts; agri. growth slows and then declines; migration and pauperization of the poor is accompanied by depopulation of entire clusters of villages. Water quality problems assume serious proportions; the `smart' begin moving out long before the crisis deepens; the poor get hit the hardest.
Interventions	Targeted subsidy on pump capital; Public tubewell programmes; Electricity subsidies and flat tariff	Subsidies continue. Institutional credit for wells and pumps. Donors augment resources for pump capital; NGOs promote small farmer irrigation as a livelihood programme	Subsidies, credit, donor and NGO support continue apace; licensing, siting norms and zoning system are created but are weakly enforced. Groundwater irrigators emerge as a huge, powerful vote-bank that political leaders cannot ignore.	Subsidies, credit and donor support reluctantly go; NGOs, donors assume conservationist posture zoning restrictions begin to get enforced with frequent pre-election relaxations; water imports begin for domestic needs; variety of public and NGO sponsored ameliorative action starts.

Figure 1. Rise and decline of groundwater socio-ecologies

well interference, numbers of wells and resource depletion. However, the groundswell of demand for groundwater was so overwhelming, that India's policy makers have thrown their lot in with the farmers, providing them with all manner of subsidies and concessions to invest in groundwater irrigation. When (and where) the resource has come under threat, they have kept paying lip service to the ideal of sustainable groundwater management but in effect have all along followed the Texan rule of 'letting the locals figure it out for themselves' (Shah, 2006). This paper is a preliminary exploration of how India's 'locals have figured groundwater out for themselves'. The overarching hypothesis, still tentative, is that in northern India's vast alluvial aquifers, more in arid western parts and less in eastern humid areas, cooperative and community initiatives have emerged, in an opportunistic mode, more to overcome techno-economic constraints to unhindered development of groundwater resource for irrigation but with little community action to conserve, augment or sustainably manage the resource. In contrast, in overdeveloped hard rock aquifer areas, where groundwater overexploitation translates into everyday physical scarcity of groundwater, pockets of institutional action has been directed–in an opportunistic as well as strategic mode–to conserving and augmenting the resource (see Figure 2 for the aquifer map of India).

The narrative described in this paper is not the result of one particular study or research project but of a broader reading of the evolution of the groundwater economy in various parts of India in comparison to other major groundwater using countries such Pakistan, Bangladesh, China, Mexico and the United States over a 30- year-long engagement with this phenomenon. A larger backdrop to the ideas presented are available in Shah (2009). The basic analytical method used is of comparative

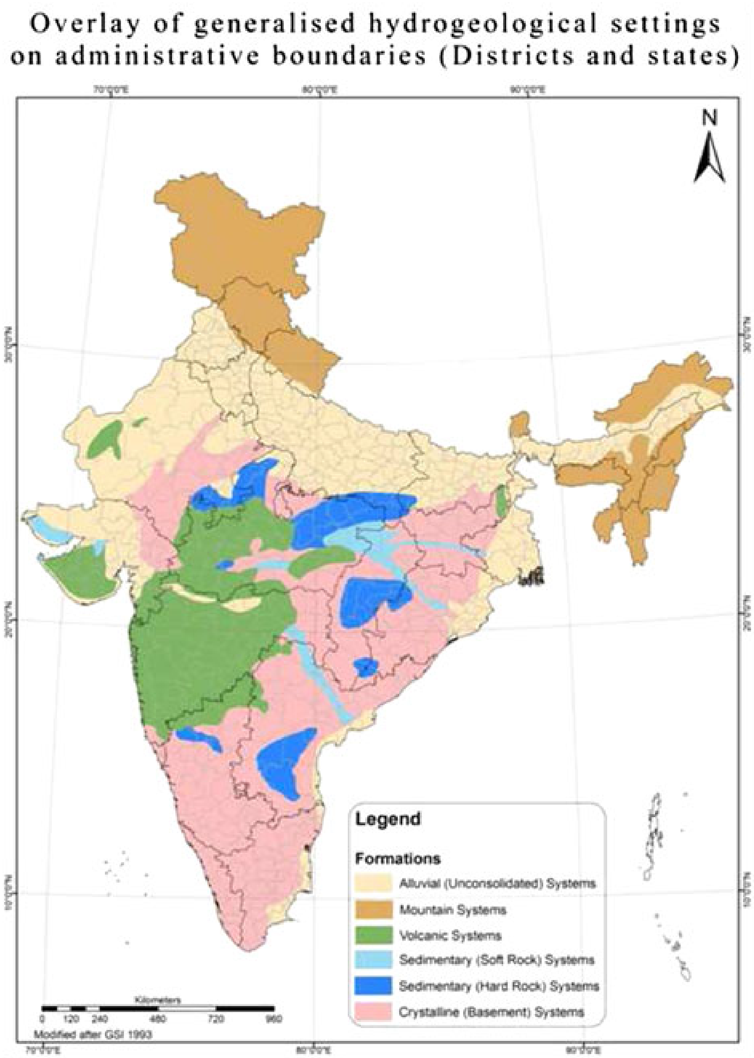


Figure 2. Aquifer map of India (Source: Kulkarni *et al*., 2009)

analysis of different geographies, asking 'what is the same? What is different? Why?'

FIVE SITUATIONS

Hydrogeologists have evolved a wide variety of models to understand human impacts on aquifer behaviour. However, equally interesting and important is the impact of aquifers on human behaviour. Since 1970, the intensive exploitation of groundwater for irrigation has brought its users face to face with the aquifer. Most Indian farmers have no *formal* scientific understanding of groundwater hydrology; yet they have to *intuitively* devise ways to cope with and adapt to the changes in aquifer conditions as groundwater withdrawals have increased. How have they coped with and adapted to these changes? Are the coping and adapting patterns of farmers in, say, Bihar, the same as those of farmers in Punjab or in Tamil Nadu. Or do they differ in some systematic manner? These questions have not been explored sufficiently in India or elsewhere.

Shah (2009) outlined five situations in which we can distinguish systematic patterns of 'coping and adaptation', as detailed below.

(a) Ganga–Meghana–Brahmaputra (GBM) basin

The GBM basin represents one of the world's richest aquifer systems, providing access to virtually limitless quantities of fresh groundwater at convenient depths. In the 1970s, scientists called this the 'Ganges Water Machine' and argued that planned groundwater abstraction after every monsoon in the region could create massive storage that would fill up with monsoonal recharge and obviate the need for building surface storages (Ravelle and Laxminarayan, 1975). Yet, the basin is home to some 40 billion agrarian poor (Shah, 2001). The institutional dynamic of groundwater irrigation in this heavily recharged aquifer system is best described as *atomistic individualism*. Each farmer who abstracts groundwater has little or no impact on other users and vice versa. As a result, groundwater users fail to coalesce into an aquifer community in which all users are 'mutually vulnerable and mutually dependent because of the centrality of resource use in supporting livelihoods' (British Geological Survey, 2004). Good examples of these conditions are eastern Uttar Pradesh, North Bihar and North Bengal. There are isolated examples of community action or cooperation in this geographical area (Pant and Rai, 1985; Boyce, 1987; Ballabh, 1989; Palmer-Jones, 1999) but these are invariably catalysed by NGOs and sustained by subsidies and external support. Most have withered away as soon as the external props were withdrawn.

(b) Arid alluvial aquifers in western and north-western India

Large parts of the Indus basin are underlain by deep sandy alluvial formations with vast capacity for groundwater storage. However, compared to the Ganga basin, these receive less rainfall and snowmelt for groundwater recharge. These regions are excellent for extensive shallow groundwater use. Indeed, Pakistan and Indian Punjab, Haryana, parts of Rajasthan and northern Gujarat are areas in which agriculture prospered with irrigation from shallow open wells during the colonial era. With expansion in groundwater irrigated areas, farmers have been chasing falling groundwater levels. This has increased the cost of groundwater production without greatly reducing water availability and, in many cases, quality. Since the capacity to invest in chasing declining water levels is the precondition to survival in the groundwater irrigation economy, the resource poor have been eased out while wealthy farmers have established de facto control over the groundwater resource. The institutional dynamic of groundwater development here is best described as *collusive opportunism* among the wealthy (Prakash, 2005; Shah, 2009; Shaheen and Shiyani, 2005).

(c) Salinity-prone aquifers that force exit from irrigated agriculture

There are substantial swathes of high-storage alluvial aquifers with limited amounts of fresh water. Many coastal aquifer systems, such as coastal Saurashtra in Gujarat, fall into this category. Here, rapid groundwater development initially proved profitable; but then water quality deteriorated so rapidly that in many areas irrigated farming has either shrunk or been given up altogether. Pervasive negative expectations about the future of groundwater have inspired extreme fatalism, hopelessness and despair. A strong sense of interdependence has created an aquifer community, but despair is driving it towards disintegration.

(d) Hard rock aquifers inducing rivalrous gaming

Upon intensive development of groundwater, farmers in hard rock areas suffer increased costs as well as reduced availability of groundwater. This condition promotes intensive competition and rivalry among competing users. For new entrants to the groundwater economy, finding a site for a successful borehole becomes a life-and-death issue that has caused many a farmer's suicide in the Vidarbha, Telangana and Rayalaseema regions. Irrigators are intensely aware of their interdependence on a limited but shared resource. This is manifested in 'competitive deepening' of wells (Janakarajan, 1994; Vaidyanathan, 1996), crowding of new wells near a recharge source or successful wells (Chandrakanth *et al*., 2004) or 'borewell-blasting' to enhance borewell yield. Groundwater users in these areas have many characteristics of an aquifer *community*, but a dysfunctional one; and user adaptation is best described as rivalrous gaming.

(e) Hard rock or confined aquifers inducing cooperative gaming

Under certain circumstances, rivalrous gaming among groundwater abstractors metamorphoses into cooperative gaming that reduces the cost and risk of groundwater production and augments water availability to the entire aquifer community. Examples of such cooperative gaming on a fairly large scale are to be found in the Saurashtra peninsula of Gujarat, and Alwar District in eastern Rajasthan. In both of these cases, hundreds of village communities pursued a loosely coordinated campaign of aquifer rejuvenation, with or without government support but invariably with the help of an external catalytic agent to improve the groundwater regime over an area that spanned several tens, or even hundreds, of thousand hectares of farming land. In both these cases, initial positive experience with decentralized groundwater recharge generated a groundswell of social energy. Positive expectations created a strong sense of benign interdependence and highly functional aquifer communities for local groundwater self-governance. While by far the majority of such experiments have focused on enhancing natural recharge, at least one large-scale experiment in hard rock Andhra Pradesh also made significant strides in involving over 700 village communities in groundwater monitoring and its demand-side management.

COMMUNITY RESPONSE IN ARID ALLUVIAL AQUIFERS

During the mid-1980s, when the trend throughout India was for numbers of borewells to increase, for shallow tubewells to be replaced by deep tubewells and groundwater levels to fall relentlessly, the trajectory of groundwater development suggested an inevitable and rapid transition of pre-development aquifers from groundwater boom to an immiserizing bust. David Seckler (Seckler *et al*., 1999) had forewarned that a quarter of India's food basket was at risk from unsustainable over-exploitation of groundwater. Sandra Postel had argued India's groundwater economy was resting on 'pillars of sand'. This doomsday drama is now playing out in many theatres of rural India; and the progression of socio-ecological and institutional developments is now regular and predictable, as outlined in Figure 1 which was first published in 1996 (Burke and Moench, 2000).

The two Figures (3 and 4) from Columbia University's Earth Institute (Modi *et al*., 2011) show one example of this situation from Mehsana District in north Gujarat. Figure 3 shows persistent decline in groundwater level from 1976 to date, based on a survey of 170 tubewell owners. Figure 4 shows the increasing energy intensity of groundwater irrigation, from less than 2000 kWh to deliver 600 mm of water to a hectare, to between 10,000 and 12,000 kWh today. Groundwater irrigation continues apace because by deepening tubewells and installing ever larger pumps, farmers can maintain water yields while energy costs remain capped through power subsidies.

The size of the agrarian economy grows rapidly based on booming groundwater irrigation. Government policies that support such a boom, in the form of subsidies, credit and other measures, continue well beyond the stage when signs of over-development and unsustainability become clearly visible. Pre-monsoon water tables register secular decline, as natural recharge falls increasingly short of annual abstractions. The density of groundwater structures–number of mechanized wells per 1000 ha of net cropped area–keeps growing well beyond the sustainability threshold. As the peasantry experiences an agrarian boom fed on the opiate of subsidies, reducing or removing these becomes an increasingly political issue. As costs of chasing declining groundwater levels soars, groundwater resource as well as subsidies provided to develop and use it are pre-empted and monopolized by the rural rich (Dubash, 2002; Prakash, 2005). Competitive groundwater markets, which made groundwater irrigation highly equitable in early stages (Shah, 1993; Meinzen-Dick and Sullins, 1994), now shrink, become monopolistic and emerge as the instrument of smallholder exploitation by the wealthy (Shah, 2009; Nagaraj *et al*., 2005). In the final phase, the persistence of farmers in over-exploiting aquifers dramatically raises the social and economic cost of energy needed to pump deep groundwater and the environmental costs of dried up wetlands, declining lean season flows, water quality deterioration and the resulting deleterious impacts on public health. Arid alluvial aquifers present groundwater users with neither the incentives nor the compulsion to organize themselves to reverse, or even arrest, the persistent depletion of their aquifer, and imminent decline in their agrarian economies. If they do organize, it is either to preserve and enhance energy subsidies so that they can keep chasing the falling groundwater levels (Joshi and Acharya, 2005) or to share the huge risks and capital investment needed to access falling groundwater (Shah and Bhattacharya, 1993; Dubash, 2002; Prakash, 2005; Birkenholtz, 2009). Individually, the more enterprising rural farmers undertake a generational transition to move their household economy from agriculture to non-farm livelihoods (Prakash, 2005). What scientists consider to be the best aquifers–deep sandy alluvial material with high storage capacity–inspire the strongest sense of passive opportunism among their users. There is collective action here but only to continue exploiting the depleting resource. Hard rock aquifer areas are interesting because in here we find a collage of individual or institutional responses directed to sustain the resource and lengthen the aquifer life.

COMMUNITY RESPONSE IN HARD ROCK OR CONFINED AQUIFERS

Since the beginning of the 1990s, India has experienced numerous spontaneous and induced attempts by groundwater

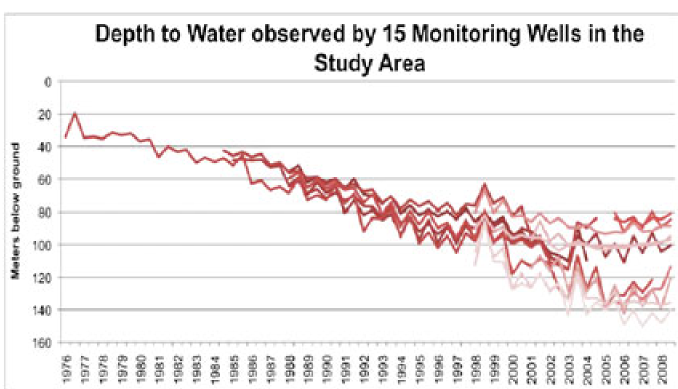


Figure 3. Secular decline in water level in 15 wells in Mehsana, North Gujarat

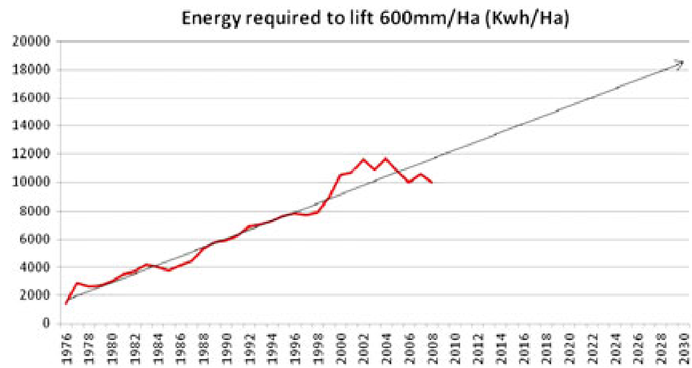


Figure 4. Increase in energy required to pump groundwater, Mehsana, North Gujarat

users to counter the dominant tendency for relentless aquifer depletion. A large number of these are small-scale attempts encompassing one or a few villages. The Ralegao Siddi (Sharma, 2006) and Hirwebazaar experiments (Deulgaonkar, 2004) in western Maharashtra are examples of how arrest and reversal of the 'depletion syndrome' can rejuvenate aquifer systems as well as those economies dependent on them. Large-scale watershed programs implemented by central and state governments as well as by scores of NGOs learnt from these experiments but mostly failed to reproduce their magic, primarily because of poor implementation and failure to work up the necessary level of participation. However, two instances of large-scale popular mobilization for decentralized groundwater recharge in western India over the past two decades lend support to a hypothesis advanced by Michael Lipton (1985) that when overuse of a common property resource 'bottoms out', users find it easier to organize to improve the resource, and adopt and enforce norms for its sustainable use (see Figure 5).

Unlike in alluvial aquifer systems, where well interference becomes a critical issue only after substantial crowding of tubewells, in hard rock aquifers, well interference emerges as an issue in the early stages of a groundwater boom. In alluvial aquifers, as the water table aquifer is depleted, shallow wells dry up and the only option for their owners is to abandon them. In hard rock aquifers, well interference results in competitive deepening of wells. Well owners, acutely aware of their interdependence, vigorously pursue individual strategies of maximizing their share in a limited storage aquifer. A common method is to drill several horizontal bores inside the open well to enhance connectivity between their wells and water-bearing pores. Krishnan (2008) describes specialist gangs of workers from Rajasthan who are commissioned to undertake this work with horizontal bores. In Karnataka, a mechanic skilled in doing such work became well known as an *addabore* (lateral bore). In southern India as well as in Saurashtra, borewell blasting and aquifer blasting to increase rainwater storage and well yields has become popular among farmers. Siting successful wells becomes a challenge in overdrawn hard rock aquifers. There are a multitude of stories of farmers who have drilled dozens of boreholes before striking water. New wells tend to be sited close to existing successful wells, or near a tank or a rainwater harvesting (RWH) structure. It is also common for farmers to buy small pieces of land near a river or a tank to make a borehole to transport water by pipes for irrigation. Tubewell owners in over-developed alluvial aquifer areas observe little impact from either a major increase of rainfall or drought on the yield of their tubewells. In contrast, in many hard rock aquifer areas, a good monsoon revives abandoned wells; and a drought leaves even deep wells dry.

In a comparative study of farmer responses in alluvial Punjab and hard rock Telangana in Andhra Pradesh, Fishman *et al*. (n.d.) noted that in the Punjab, 'water table dynamics are dominated by declining trends', while in Telangana these 'dynamics are dominated by short-term fluctuations'. Further,

> irrigation from the deep aquifers (of Punjab) is largely unaffected by fluctuations in water tables and rainfall, but in the hard rock shallow aquifers irrigation is more variable and sensitive to these stochastic variables. . . . Over-exploitation of a deep aquifer is primarily an issue of long-term sustainability, whereas in a shallow aquifer, it leads to increased *short-term* variability in irrigation and a loss of buffering capacity.

Fishman *et al*. (n.d.) conclude that the irrigation dynamics are affected by the time it takes to reach the 'bottom' of the aquifer. Where aquifers are 'thick' as in the Punjab, the impacts of falling water tables translate into rising energy use and cost of pumping. In contrast, in 'thin' aquifers of Telangana, the 'bottom' is reached at the early stages of the groundwater boom and farmer behaviour is conditioned by the physical scarcity of groundwater. In the Punjab, water table dynamics are dominated by a declining trend, the familiar symptom of over-extraction.

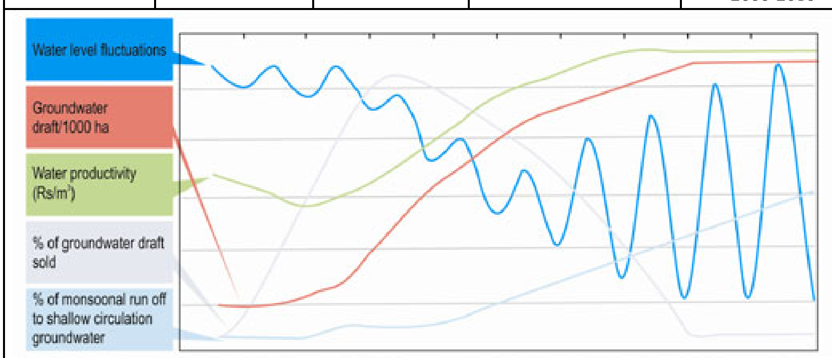
In Telangana, they are dominated by a high degree of short-term fluctuations and there is no clear long-term trend. While water tables show a net decline on an 'average' year, the trend can be reversed by one or two consecutive 'wet' monsoons that can largely recharge the aquifers. 'In shallow aquifers [of Telangana], water tables cannot decline consistently because they reach the bottom and also because they can be recovered by one or two seasons of abundant rains.'

Fishman *et al*. (n.d.) are also concerned that '... in shallow aquifers, the initial development of irrigation can provide such a buffer, but if excessively developed, can also undermine it'. When this happens, farmers first exhaust all available avenues to maximize their share in the limited aquifer resources; then (see in Stage 2, Figure 1) they try a variety of ways to enhance recharge and maximize their share in it. A growing movement to convert centuries-old irrigation tanks into recharge tanks in hard rock districts of Andhra Pradesh (Anantpur and Chittoor districts) (Reddy, 2005) and Karnataka (Kolar District) (Nagaraj and Chandrakanth, 1997) is indicative of this trend as is the propensity of new wells to crowd around tanks and streams.

When all of these potential sources are exhausted, grounds become fertile for all manner of social experimentation in adaptive self-management of aquifers, surface water bodies and rainfall in a conjunctive mode (as highlighted by Stage 4 in Figure 1). India has witnessed many examples of such experimentation; but all are confined to the so called 'thin' aquifers. There is no evidence of such activities in deep (or 'thick') alluvial aquifers. As van Steenbergen and Shah (2003: 242) note, 'Particularly where the impact of recharge or pumping is immediate and dynamic, self-regulation has developed.' Self-regulation can focus on demand-side measures–in which users are restrained from unbridled pumping, or supply-side–in which users are enjoined to contribute to enhance the resource.

By far the best example of demand-side self-regulation of any significant scale is Andhra Pradesh farmer-managed

Stages	I Private Exploitation 1960-75	II Competitive Exploitation 1975-90	III Recognition of Interdependence 1987-2010	IV GW-centric Adaptive Water Management 2000-2010



Driver of farmer and community behavior	Utilize groundwater to improve livelihoods	Maximize one's share in a shared but limited aquifer space	Augment own and shared groundwater resource	Adapt farming system to changing GW availability
Examples of Farmer Adaptive Behavior	well-irrigation spreads; innovations in well-digging and boring; drilling costs fall; water markets emerge	Competitive deepening; boring within wells; storage wells; horizontal bores; bore-blasting; aquifer fracturing;	Private recharge; community recharge; sub-basin recharge; irrigation tanks and canals for recharge; canal systems valued for recharge more than irrigation.	GW-irrigated area follows rainfall with a seasonal lag; High value market crops; micro-irrigation; Dairying, poultry, sericulture, spices, fruit/veg.
Govt. policies	Capital and power subsidies	Subsidies continue; half-hearted regulation	Watershed mgt; support decentralized recharge; ration farm power supply	Farm power scarcity becomes GW regulator; Managed Aquifer Recharge
Groundwater institutions	Buyers' market for irrigation service	Sellers' market; well owners make a killing	Irrigation service against 1/4th or 1/3rd crop share	Irrigation service for share in high value market crops

Figure 5. The process of emergence of groundwater-centric adaptive water management in some hard rock aquifer areas of India

groundwater systems (APFAMS), in which a group of NGOs have involved farmers in over 700 villages in over-exploited hard rock areas in a programme of understanding and monitoring their groundwater resources, and planning their agricultural operations such that they are consistent with the resource regime.[1] This much acclaimed programme has undoubtedly deepened and formalized farmers' originally intuitive knowledge of groundwater processes. However, evaluations by the World Bank (2010) and others suggests that significant change in farmer behaviour has also occurred, manifested in a reduction in aggregate groundwater draft as well as shifts to cropping patterns that are less water-demanding (van Steenbergen, 2010).

While demand-side 'self-regulation' is still rare, there are several examples of spontaneous supply-side self-regulation. One such example is the large-scale construction of *johads* (ponds) by local communities in the Alwar District of Rajasthan, as a strategy to revive and sustain groundwater-based agrarian livelihoods. The catalytic agent was Tarun Bharat Sangh (TBS), a local NGO, which began mobilizing rural youth trapped in a spiral of unemployment and poverty caused by depleted aquifers. When the first cluster of *johads* produced unexpected results in terms of improved availability in open wells for irrigation and surface water for livestock, the message spread like wildfire and TBS was able to quickly upscale its *johad*-building mandate to 550 villages, constructing 2000 *johads* and revitalizing the local agrarian economy spanning 6500 km^2 and turning Arvari, a euphemeral stream, into a perennial river (van Steenbergen and Shah, 2003). So overwhelming was the enthusiasm and positive expectation created by the movement that TBS was able to coalesce all the participating villages into a basin organization called the Arvari Parliament, which made and enforced rules about demand-side management of water in the basin. The Alwar experiment has been extensively researched and has received awards.[2] However, after a detailed study, a senior hydro-geologist (Athavale, 2003) argued that the basis for large-scale build up of popular support for the *johad* movement was an impervious layer some 9 m below ground level which ensured that percolation and infiltration from *johads* stayed in large part to become available as groundwater in wells.

By far the most energetic and inspired response to the intensification of groundwater scarcity globally has come in the form of a mass movement for well recharge and water conservation in Saurashtra in Gujarat, India. The Saurashtra recharge movement was first catalysed by a Hindu religious teacher presiding over a loosely formed sect called the Swadhyaya Pariwar and subsequently joined by other sects of Hinduism, and also by scores of NGOs and grassroots organizations in the aftermath of the 3-year drought of 1985–1987. The simple and effectively conveyed message was: `If you quench the thirst of Mother Earth, she will quench yours.' In large congregations, hundreds of thousands of farmers were exhorted to adopt the credo: 'The rain on your roof, stays in your home; the rain on your field, stays in your field; rain on your village, stays in your village'. At the end of a 3-year drought, farmers were willing to act on advice from any credible source. Thousands of farmers modified their large open wells for receiving flood waters from rain; small check dams were built; some underground dykes were tried too. The monsoon in 1989 was good; and the investment of all these efforts paid rich dividends as many water harvesters not only gave a life-saving irrigation to their rainy season crop when the monsoon withdrew early, but had water in their wells for a *rabi* (winter) crop too. This spurred thousands of other farmers to follow suit. By the mid-1990s, community-based groundwater recharge had become a mass social movement. Cement factories offered free cement for common property RWH structures. Rich diamond merchants from Brussels, originally from Saurashtra, offered cash support. The state government also jumped on the bandwagon and devised a flexible scheme that offered village communities support to construct large check dams. All the while, some hydro-geologists were lukewarm (Kumar *et al*., 2008); they argued that Saurashtra's hard rock aquifers had too little storage; and much of the recharge would spill out of the wells as well as move laterally underground to the sea. In fact, the limited storativity of Saurashtra's aquifers has sustained farmer enthusiasm; when they see their efforts with RWH showing in over-spilling wells, their faith in RWH is continually reinforced.

So beneficial has the experience been with community based groundwater recharge in hard rock Saurashtra area that check dam construction has become the official policy of the Government of Gujarat. The scheme, known as the Sardar Patel Community Water Harvesting Scheme, performed best in the Saurashtra and Kachchh regions; but for the state as a whole, by December 2008, nearly 500,000 water harvesting and recharge structures were constructed–113,738 check dams, 5 *bori bandhs*,[3] 240,199 farm ponds, as well as 62,532 large and small check dams constructed by the Water Resources Department of the Government of Gujarat[4]–all in a campaign mode. During recent years when much of India has been experiencing secular decline in groundwater levels, Gujarat is the only state in which the groundwater regime has been improving in many areas. Figure 6(a), based on water level fluctuation data collected three times a year by India's Central Ground Water Board (CGWB), shows pockets in which groundwater was declining even during the monsoon period in 2000. Figure 6(b) shows changes in water levels during May–November 2008; throughout hard rock Saurashtra, groundwater level was rising during this period. Some of this rise was arguably the result of the water harvesting and recharge movement that the people of Saurashtra had engaged in with assistance from the state government.

(a) (b)

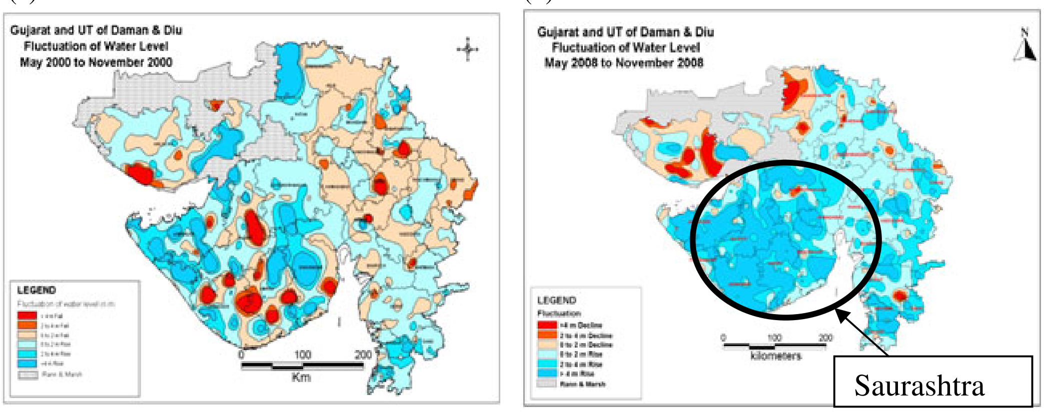


Figure 6. Improvement in groundwater situation in hard rock areas of Saurashtra, Gujarat

CONCLUSION

India is experiencing a curious socio-ecological dynamic in its groundwater economy. In thick sandy alluvial aquifers considered 'good' by scientists, the pattern of groundwater development is becoming unsustainable, with secular and persistently falling groundwater levels and little response from groundwater users to arrest or reverse the trend. Instead, in 'thin' and hard rock aquifers, which the CGWB had declared 'unworthy of development' during the 1960s, there are pockets in which groundwater user communities are responding in ways that make the groundwater economy sustainable in the long run.

A broad reading of disaggregated trends in the evolution of the groundwater irrigation economy in India (taken in conjunction with Pakistan, Bangladesh and Terai Nepal) permits the following testable propositions about which kinds of institutional initiatives emerge in which hydro-geological settings:

(1) In humid alluvial aquifer areas, with abundant and easily accessible groundwater aquifers, the sense of aquifer level interdependence failed to emerge among irrigators who neither felt nor behaves like an 'aquifer community'. Externally catalysed and sustained cooperative initiatives to improve poor people's access to groundwater irrigation withered away under the onslaught of highly competitive irrigation service markets. This is evident in the decline of community wells in eastern Uttar Pradesh and Bihar (Ballabh, 1989; Pant, 2005), USAID-supported lift irrigation schemes in Nepal (Gautam, 2006) and tubewell groups promoted by PROSHIKA in Bangladesh.

(2) In arid alluvial aquifer areas with porous aquifers but limited recharge, accelerated groundwater development resulted in a rapid decline in groundwater levels and deterioration in water quality. While populations inhabiting these regions coped with water quality deterioration, continued irrigation with groundwater necessitated two things: (a) sharing the risk and increasing capital cost of accessing groundwater; and (b) controlling the energy costs of pumping to keep groundwater-irrigated agriculture profitable. Almost all examples of local community organization in those arid alluvial aquifers of India studied by researchers are designed to address (a). Similarly, large-scale political mobilization of the peasantry in western India around farm power subsidies and improved hours and quality of power supply has emerged to address (b). There is no sign either in humid or arid alluvial aquifer areas of significant community initiatives to support the sustainable management of groundwater.

(3) This can be said about most hard rock areas, which constitute over two-thirds of Indian land mass. However, in recent years, there have been sporadic examples–some of them expanding spatially in many directions–that suggest initiatives to either conserve or augment the resource (Saurashtra) or to manage the demand (APFAMS) or both (Ralegao Siddi or Hiwre Bazar). Most began as spontaneous responses; some were consolidated and sustained by civil society formations; a few, such as in Saurashtra (Gujarat) were co-opted by the state but still maintained their original ethos.

Community organizing and institutional responses in alluvial aquifer areas (represented by the first two cases) must be counted as opportunistic. Farmers, catalysts and NGOs engaged in these were all concerned about access to irrigation, and not about the sustainable use of groundwater.

In hard rock aquifer areas too (the third situation), opportunism was and continues to be rampant. However, the everyday consequences of unfettered opportunism seem, in some geographical areas, to have persuaded a sufficiently large section of the community to participate in strategic initiatives that may or may not benefit each member equally.

NOTES

1. For more information, visit http://www.fao.org/nr/water/apfarms/index.htm
2. For example, a recent PhD thesis for an Australian university (Glendenning, 2009) examined the impact of 366 johads in a 476 km^2 area and found the average daily potential recharge from RWH structures was between 1 and 52 mm day^{-1} while recharge reaching the groundwater was between 3 and 7 mm day^{-1}; approximately 7% of rainfall is recharged by RWH in the catchment. The analysis shows that as the RWH area increases, it reaches a limiting capacity from where developing additional RWH area does not increase the benefit to groundwater stores, but substantially reduces streamflow. Nevertheless, RWH in a system increased the overall sustainability of the water demand for irrigated agriculture, compared to a system without RWH. Also RWH provided a slight buffer in the groundwater store when drought occurred.
3. Small check dams constructed with sand bags.
4. http://guj-nwrws.gujarat.gov.in/pdf/check_-demo_240309.pdf

CONFLICT OF INTEREST

The author has no conflicts of interest to declare.

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