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Sustaining Asia's Groundwater Boom: An Overview of Issues and Evidence

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Abstract

This article suggests that Asia's groundwater socio-ecology is at an impasse. Rapid growth in groundwater irrigation in South Asia and the North China plains during the period 1970–1995 has been the main driver of the agrarian boom in these regions. India, Pakistan, Bangladesh and China account for the bulk of the world's use of groundwater in agriculture. On the plus side, groundwater development has provided sustenance to agrarian economies and millions of rural livelihoods. On the downside, it has created chronic problems of resource depletion and quality deterioration. While problems of groundwater depletion, pollution and quality deterioration are indeed serious, so are the consequences of the degradation of the resource for those that have come to precariously depend upon groundwater irrigation.

Three problems currently afflict groundwater use: depletion due to overdraft; water logging and salinization; and pollution due to agricultural, industrial and other human activity. The pathology of the decline in groundwater socio-ecology reflects a remarkably similar pattern across regions. The critical issue for Asia now is: what might be done to sustain and revive these groundwater socio-ecologies vital to the region's economy? This article reviews a variety of techno-institutional approaches. However, transposing lessons from the industrialized world uncritically in the Asian context may not work. A more nuanced understanding of the peculiarities of Asia's groundwater socio-ecology is needed.

Keywords: Asia; Groundwater; Socio-ecology; Groundwater depletion; Waterlogging; Groundwater pollution.

1. Contours of the Asian groundwater economy

Groundwater has come to be the mainstay of irrigated agriculture in large parts of Asia. Between them, India, Nepal, Bangladesh, Pakistan and China use over 300 km^3 of groundwater annually, nearly half of the world's total annual use. While in the rest of the world, the bulk of groundwater use is urban and industrial, in Asia it is mostly in agriculture, and groundwater irrigation is a US$ 25 billion business in Asia (Table 1). Another dimension of Asia's groundwater irrigation, is the large variation in use patterns. In Southeast Asia, which has abundant surface water, groundwater is of little importance. Nevertheless, in nearly all of India, northern Sri Lanka, Pakistan (Punjab) and North China, it has come to play a unique and increasingly critical role in supporting a dynamic agriculture. In India, about 60% of total irrigated area is served by wells and tubewells. On the North China plains, groundwater was extracted from some 3.3 million tubewells to irrigate an area of 14 million hectares by 1997 (Shi, 2000), and accounted for 65%, 70%, 50% and 50% of total agricultural water supply in the provinces of Beijing, Hebei, Henan and Shandong respectively (Government of China, 2000). Tubewell irrigation has helped this region to maintain a fairly high agrarian — and, indirectly, industrial — growth rate. In Pakistan, groundwater provides over 40% of the total crop water requirements in the densely populated province of Punjab, producing 90% of the country's food (Qureshi and Barrett-Lennard, 1998).

Throughout Asia, the history of protective well irrigation goes back millennia. However, intensive groundwater use on the scale that we find today is a story of the past 40 years. In Hebei Province of China, the number of mechanized wells grew by a factor of more than 1,000 over 43 years — from a mere 730 wells in 1955 over 840,000 in 1998. In India, the total number of mechanized wells and tubewells grew from a small fraction of a million in 1960 to some 19 million in 2000. In the Punjab, Pakistan, the number of the wells increased from barely a few thousand in 1960 to some 500,000 today.

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Table 1. The size of the agricultural groundwater economy of India, Pakistan, and China

		India	Pakistan	China
A	Total number of groundwater structures (million)	19	0.5	3.5[a]
B	Estimated groundwater use (km^3)	150	59	106[b]
C	Average output of groundwater structures m^3/hour	25	100	41[c]
D	Average hours of operation/well/year [(B*10^9)/A]/C	315	1180	1134[c]
E	Price at which pump irrigation from standard-sized pump sells (US$/hour)	1	2	0.96[c]
F	Imputed value of groundwater used/year (B/C*E) or (E*D*A) (bn US$)	6	1.2	2.5

Sources: [a]Shi (2000), [b]Govt. of China (2000), [c]Wang (2000).

Along with this meteoritic spread of wells and tubewells, the groundwater economies in the predominantly agrarian regions of South Asia and North China have boomed. This has assumed great significance not only for the livelihoods and food security of the poor, but also as an engine of rural and regional economic growth. There are several ways to consider the scale of the groundwater economy, but one practical measure is the economic value of groundwater production. India, Pakistan and Bangladesh have active markets in pumping and irrigation services, in which tubewell owners sell groundwater for irrigation to their neighbours at a price that exceeds their marginal cost of pumping. This price offers an approximation of market value of groundwater use in irrigation. Table 1 constructs a profile of the groundwater economy in three Asian countries (India, Pakistan and China) using such valuation and suggests that groundwater irrigation in Asia may well be a US$ 10–12 billion/year business. If we consider farmers' earnings from selling groundwater for irrigation, the ultimate contribution of groundwater to the Asian agricultural economy may be more nearly US$ 25–30 billion/year. Thus, the groundwater economy of South Asia is huge and is mainly in the hands of the farmers.

The Asian groundwater economy has emerged as a spontaneous response to a need felt by millions of farmers. As a result, it exists entirely within the private and informal sectors, with no, or very limited, regulation. Few people realize that the value of private capital investment in groundwater structures approaches two-thirds of public investment in surface irrigation. Over the past 50 years, private groundwater investments by farmers in India, for example, may well be on the order of US$ 12 billion.[1] This compares to public sector investment for irrigation of US$ 20 billion. However, financial and economic benefits from the former are considered many times greater. Thus, in the Punjab (Pakistan), for instance, capital investment in private tubewells is estimated to be some Pak.Rs. 25 billion (US$ 400 million at 2001 prices)[2] whereas, according to one estimate, annual benefits in the form of agricultural production approaching Pak.Rs. 150 billion (US$ 2.3 billion) accrue to over 2.5 million farmers, who either own tubewells or rent irrigation services from their neighbours.[3]

In general, one m^3 of groundwater applied to crops is significantly more productive than one m^3 of surface irrigation. There are many reasons for this. Groundwater needs little transport, being produced where needed. It offers irrigation to an individual farmer 'on demand,' something few surface systems can do. In addition, because its use entails a significant incremental cost to farmers to lift, they tend to economize on its use and maximize application efficiency. Evidence in India suggests that crop yield/m^3 on groundwater irrigated farms tends to be 1.2–3 times higher than on surface water irrigated farms (Dhawan, 1989). Similar evidence is available from other parts of the world as well.[4] Groundwater users in South Asia often use only a small fraction of the scientifically recommended water requirements for their crops, yet are able to obtain whopping increases over rainfed yields. This is due to the high marginal cost of groundwater use in water-scarce regions. Some of the poorest irrigators in South Asia — who purchase irrigation water from neighbouring well-owners — commonly pay US$ 0.10–0.14/m^3 of water compared to a fraction of a cent paid by canal irrigators. The most privileged, however, are farmers who can resort to a judicious combination of surface and groundwater for their irrigation. A study by the International Water Management Institute (IWMI) is currently being conducted on the productivity, in quantity and economic value, of 521 canal-irrigated farms in the Indus system in the Punjab (Pakistan). The study indicates that farmers with wells obtain 50–100% higher yields per acre and 80% higher value of output per acre compared to canal irrigators without wells.[5]

Finally, for national policy makers under pressure to reduce rural poverty, groundwater-based smallholder irrigation has greater appeal than large surface irrigation projects. For one, it is easier to target groundwater access to poor households than it is to target surface irrigation access as, by their very nature, surface irrigation systems tend to create islands of affluence whereas groundwater-induced

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[1] Calculated as 19 million structures @ US$ 600 each.

[2] Exchange rate (September 2001): US$ 1.00 = Pak Rs 65.

[3] R.H. Qureshi, personal communication.

[4] See Hernandez-Mora et al. (2001) for a comparative study of Andalucia, southern Spain.

[5] R.H. Qureshi, personal communication

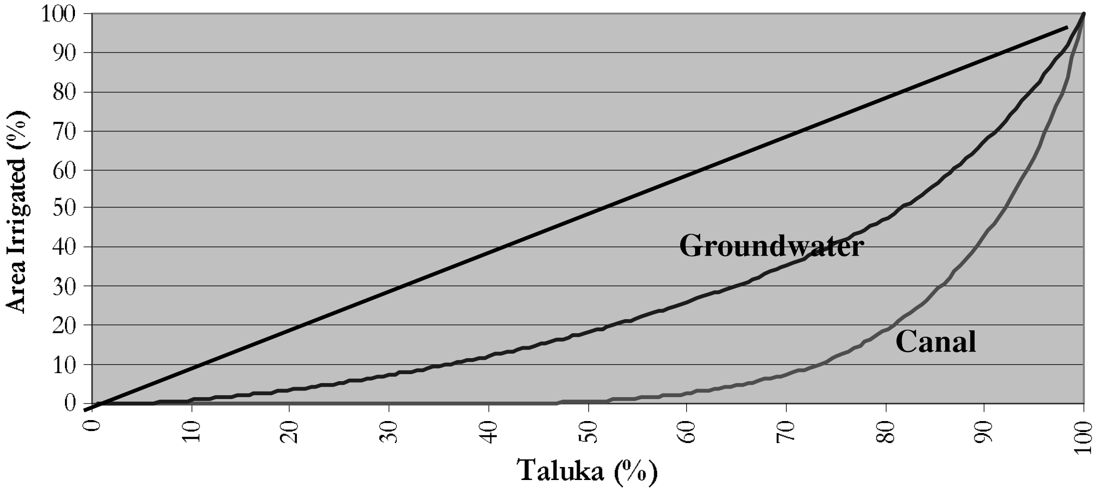


Figure 1. Cumulative percentage area irrigated by canal and groundwater in 176 districts (*talukas*) in Gujarat, India.

prosperity is spatially more evenly spread. Figure 1 shows that in the Indian state of Gujarat, 80% of the state's total canal irrigated area falls within only 20% of its *talukas* (districts*)*. Groundwater irrigated areas are also skewed spatially, but show more even distribution (Shah and Singh, 2002). No wonder, then, that in developing countries of Asia and Africa, groundwater development has become a central component of programmes to create improved livelihoods for the poor (Shah, 1993 for India; Kahnert and Levine, 1993 for the Ganges–Brahmaputra–Meghna basin; Calow et al., 1997 for Africa).

All in all, the groundwater socio-ecology has come to assume a unique role in the agrarian economies of Asia. As shown in Table 2, many countries in the world use large quantities of groundwater in agriculture (Shah et al., 2002a). However, in countries such as Iran, Mexico and USA, the proportion of the population dependent upon groundwater irrigation for their livelihood and food security is small and declining. In South Asia, in contrast, over 50–60% of the national population has come to depend directly or indirectly on groundwater irrigation. This makes it critical for these countries to ensure that the agrarian boom they have experienced in the past two decades can be sustained. However, as mentioned, indications are that this will pose complex and difficult challenges.

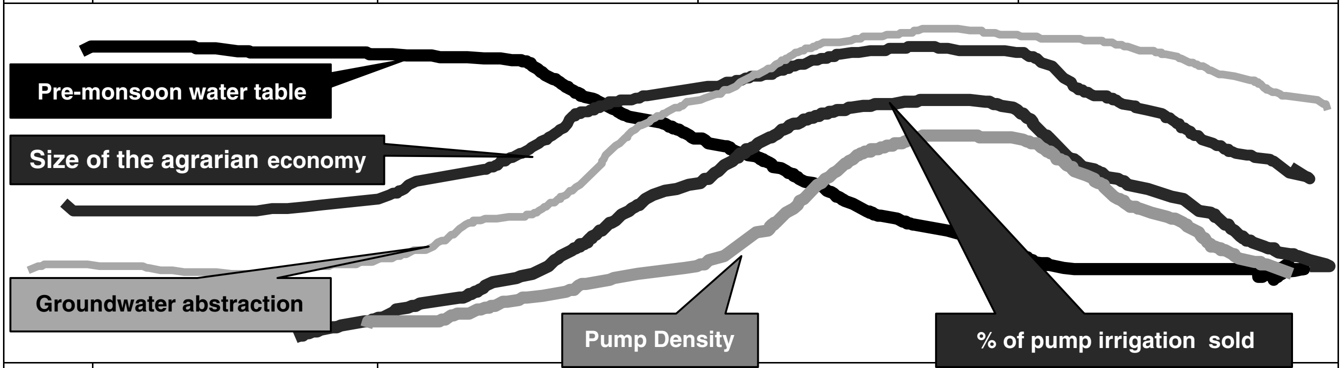
2. The pathology of decline

Nearly five years ago, David Seckler, then Director-General of the International Water Management Institute (IWMI), warned that a quarter of India's food harvest would be at risk if the nation fails to manage its groundwater properly. Today, many people think that Seckler's interference may well have underestimated the peril, and that if India does not take charge of its groundwater, the agricultural economy may crash. Sandra Postel (1999) has suggested that some 10% of the world's food production depends on a yearly overdraft of groundwater of 200 km^3; out of which 100 km^3 most likely occurs in western India. Conditions in Baluchistan are less severe, due partially to its sparse population, but in China's northern plains, the conditions are no better. Although groundwater depletion is not an immediate threat in the lower Indus basin in Pakistan and the Bhakra system in northern India, these regions suffer from soil and water salinization stemming from groundwater overdraft.

IWMI's past research on the dynamics of groundwater socio-ecologies indicates some recurring patterns. In much of South Asia, for example, the rise and fall of local groundwater economies follow a 4-stage progression, outlined in Figure 2 below. The figure illustrates the typical

Table 2. The unique role of South Asia's groundwater economy

Country	Annual groundwater use (km^3)	No. of ground-water structures (million)	Extraction/structure (m^3/year)	% of population dependent on groundwater
India	150	19	7900	55–60
Punjab (Pakistan)	45	0.5	90,000	60–65
China	75	3.5	21,500	22–25
Iran	29	0.5	58,000	12–18
Mexico	29	0.07	414,285	5–6
USA	100	0.2	500,000	<1–2



	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/degradation	Decline of the groundwater socio-ecology with immiserizing impacts.
Examples	North Bengal and North Bihar, Nepal Terai, Orissa	Eastern Uttar Pradesh western Godavari, central and southern Gujarat	Haryana, Punjab, western Uttar Pradesh, central Tamil Nadu	North Gujarat, coastal Tamil Nadu, coastal Saurashtra, southern Rajasthan
Characteristics	Subsistence agriculture; protective irrigation; 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 markets become oppressive. Private and social costs of groundwater use part ways.	The 'bubble' bursts. Agricultural growth declines; immisseration of the poor is accompanied by depopulation of entire clusters of villages. Water quality problems assume serious proportions; the 'smart' begin to move 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 tariffs.	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 and donors assume a conservationist posture. Zoning restrictions begin to be enforced, with frequent pre-election relaxations. Water imports begin for domestic needs. A variety of public and NGO-sponsored relief programmes start.

Figure 2. Rise and fall of groundwater socio-ecologies in South Asia.

progression from groundwater potential unleashing an agrarian boom, to increasing overexploitation of the resource, which finally goes overboard, because restraint is not exercised on time.

This four-stage framework indicates that Asian policy makers and managers need to make a transition from a resource development mindset to a resource management mode. Forty years of green revolution and mechanized tubewell technology have brought most of Asia to a state somewhere between stages 2 and 4. However, even today, there are substantial pockets exhibiting characteristics of stage 1. The Ganges–Meghna–Brahmaputra basin — including 20 districts of the Terai in Nepal, all of eastern and much of central India and much of Bangladesh — offers a good example. With some of the best aquifers in the world and at the same time concentrated rural poverty, governments in this region have sought primarily to stimulate an agrarian boom through groundwater exploitation (see, e.g., Kahnert and Levine, 1993; Shah, 2001). Much of South China is in a similar situation.

Many parts of western India were stages 1 or 2 in the 1950s or earlier, but have since advanced to stages 3 or 4, and the areas of Asia still in stages 1 or 2 are shrinking by the day. In South Asia, examples are plentiful of regions that are in stage 3 or even 4. An oft-cited one is North Gujarat, where groundwater depletion has set off a long-term decline in the agrarian economy. Here, some prescient, and wealthy, farmers — who perceived the impending doom — made a planned generational transition to non-farm, urban livelihoods. The poor have been left behind to pick up the pieces of what, only a decade ago, was a booming economy. This drama is being re-enacted in one groundwater socio-ecology after another with frightening regularity (Moench, 1994; Shah, 1993).

At stage 1 and early in stage 2, the prime concern is to promote the profitable use of groundwater to generate wealth and economic surplus. However, even at stage 2, attitudes need to change towards more careful management. In South Asian countries, vast regions are already at stage 3 or even 4, yet the policy regime acceptable at stages 1 and 2, has tended to persist even long after the region moves into stage 3 or even 4. IWMI's recent work on the North China plains suggests that the story is much the same there as well. The critical issue to address is: Does stage 4 always have to play out, as it has in the past? Or are there adaptive policy and management responses that, if taken at stage 2, could generate an equilibrium, in which the groundwater-induced agrarian boom is sustained without degrading the resource itself? In the remainder of this article, we will review the prospects and opportunities for forging such equilibrium.

3. Gateways to sustainability

3.1 In search of feasible solutions

The scale of groundwater depletion and degradation has long been recognized, but viable strategies for addressing the problems have not been forthcoming. Indeed, governments are still busy promoting more groundwater development. A recent research proposal at a US university on the groundwater situation in North China puts the problem thus: "For more than 20 years — since almost immediately after large-scale mechanized groundwater pumping began — Chinese scientists have observed, reported, and warned against the dangers of groundwater decline. In 1978, a network of 14,000 observation wells was established in North China. Water levels in every well are measured once every five days. Groundwater investigations at all scales, from county to regional levels, and from annual reports to huge research projects involving hundreds of hydrogeologists, have documented water-level declines, and without exception have pointed the finger at over-pumping. Decision-makers in the Land Use Bureau, the Planning Bureau, and the Water Conservation Bureau have been well informed of the problem for years. Official responses have come all the way from the highest level of the Central Government, the State Council, which in 1985 issued 'the principles of determination, calculation, collection and use of water charge for water conservancy works' expressly to address water-shortage problems. Yet, policies continue to encourage unfettered water use . . . Therefore, the most important question regarding sustainable water use in China is why policy makers ignore the groundwater crisis" (Kendy, 2000).

The foregoing aptly describes the situation in all of Asia today. If these unanswered questions are to be tackled, the focus has to be on the big picture in a multi-disciplinary research undertaking, and the prime concern must be to identify ways to operationalize sustainable groundwater management. In principle, the groundwater threat can be met, provided national administrations can build a tight resource management regime well in time that incluces both demand- and supply-side interventions. The catch is that nowhere in the world do we find such an ideal regime actually in operation. Worldwide, action is being taken in response to groundwater degradation, but it is too little, too late, too experimental, too curative, and too supply-side oriented. Precious little is being done to reduce demand for groundwater or to economize on its use.

Although the debate continues, recommended policy alternatives tend to be ineffective. Policy measures to regulate groundwater overdraft, such as enacting and enforcing groundwater laws, establishing clear tradable property rights for water, pricing of groundwater, installing licensing and permitting systems, have all been discussed *ad nauseum* at least in South Asia and China (see, e.g., Arriens et al., 1996). Nobody seems to disagree with the need for these measures, yet, no Asian country has yet been able to effectively deploy any of them even as the groundwater situation is turning rapidly from bad to worse.

3.2 Techno-institutional approaches: Learning from others' experience

The Asian debate over how to create an effective groundwater management regime has been swayed by success stories from Australia, the US and Europe. The only examples of combined demand- and supply-side interventions come from the western United States. There, some of the most extensive groundwater depletion problems in the world have occurred, and earlier than they struck anywhere else.[6] The California example provides important pointers to the rest of the world.

A major problem in transferring these lessons to a developing country context, however, is the numbers involved. In Australia and the US, the number of users is small, but

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[6] In the Santa Clara valley, south of San Francisco Bay, overdraft was estimated at 52,000 acre-feet way back in 1949, when India was still on bullock bailers and Persian wheels. The response to sustained overdraft was to create new institutions, such as the Santa Clara Water Conservation District, and a water user association. Ten dams were constructed to store flood waters for recharge; barriers of injection wells were created to prevent sea water intrusion; arrangements were made to import 100,000 acre-feet of water annually. But, apart from these supply-side interventions, there were also measures to restrict the withdrawals through the creation of groundwater zones and the levy of a groundwater tax that varied across zones according to the cost of alternative supplies. As a result, by the mid-1980s, groundwater tables stabilized at 30 feet above the historic lowest, and land subsidence was a matter of the past (Coe, 1988).

average landholdings very large. Although Europe tends to have large numbers of small users, states there have the capacity to deploy vast financial and technological resources for the protection of natural resources.

In a typical groundwater district in the US, the total number of farmers is probably less than a thousand, but in an area of comparable size in Asia, there would be over 100,000 farmers (see Table 2). The average stakes per farmer would also vary by a factor of a thousand or more. As a result, spontaneous collective action by groundwater users to protect and manage the resource is far less likely — and more difficult to sustain — in Asia. In the Murray–Darling basin in Australia, widely held as a model for integrated river-basin management, permits are mandatory for all groundwater users. But small users are allowed to extract water for domestic or livestock needs, or for irrigating small plots of 2 ha or less. If such an exemption were to be applied to in South Asia or on the North China plains, over 95% of current groundwater irrigators would be exempt (Shah et al., 2001). The large number of users is perhaps the reason that Asian and other developing country governments tend to rely more heavily on laws, rather than permits, to regulate groundwater use and abuse. However, they have yet to deliver effective regulations, either in Asia or elsewhere in the developing world.

China's new water law requires that all pumpers obtain a permit, but the law is not yet enforced. Only in deep tubewell areas of the North China plains are individual permits required of well owners. Elsewhere, a permit may be issued to a whole village, which limits its restraining effect. China's water administration is able to extract close to an economic price from canal irrigators; but groundwater is still free (Shah et al., 2002c).

South Africa's new water law and policy enshrine the principles 'User Pays; Polluter Pays', but these are yet to be operationalized. Once they are, chances are they will work well in the commercial farm economy dominated by large-scale white farms, but fail to impact areas of 'black irrigation' in the former homelands. India has been toying with a draft model groundwater bill for 20 years, but is unable to enact it into law because of doubts about the possibility of enforcing such a law on more than 19 million irrigation pumpers, scattered throughout vast rural areas.

In Mexico, the establishment of aquifer management councils (COTAS — *Consejos Técnicos de Aguas*) under the new water law and as part of the country's water reform, are a notable development. IWMI researchers in Guanjuato are both sceptical and hopeful, and believe that several factors bode ill for the future effectiveness of the COTAS in arresting groundwater depletion. Most importantly, their main role would be advisory and they would not have the mandate to resolve conflicts between water users or restrict groundwater extractions. Moreover, there is an unclear division of tasks and responsibilities between COTAS, irrigation water users' associations, the federal and state water management agencies and the river basin council. On the other hand, the COTAS provide a vehicle for groundwater users to engage in self-governance, and collective action and to find innovative solutions to the problem of groundwater depletion (Wester et al., 1999).

A more recent assessment of COTAS is less optimistic, however. Mexico's attempt to nationalize water, and create groundwater rights through the issue of concessions to all users seems to be effective in organized industry and municipalities. These sectors have the least need for such reforms. On the other hand, in the farming sector, groundwater concessions have not worked, a major problem being the high transaction costs in enforcing the concession terms on some 70,000 tubewell owners and a similar number of farmers who impound rainwater in private *bordos* (ponds) in the highlands of northern Mexico (Shah et al., 2002b). South Asia is often advised to draw a leaf out of the book of Mexico's water reform, but it is easy to imagine how difficult it would be to enforce such a regime on 19 million tubewell owners, given that Mexico is finding it difficult to enforce it on a mere 70,000 groundwater irrigators.

Institutional solutions to sustainable groundwater management that have a chance to work may pose complex issues of equity. Some of these became evident in the tiny World Bank supported Ta'iz project in Yemen's Habir aquifer. The objective of the project was to develop a partnership between rural and urban groundwater users as a mechanism for transferring water from rural areas to the city of Ta'iz on equitable terms, while ensuring sustainability of the resource. The project affected a small group of 7,000 rural residents on the Habir aquifer. While the project failed in both its endeavours — to transfer water and ensure sustainability — important lessons can be learned about why it failed. Taking an egalitarian stance, the project tried to build the capacity of all 7,000 residents to assume rights over the aquifer and manage the transfer of water to the city. However, 22 well-owning farmers opposed, frustrated or sabotaged all institutional efforts. These irrigation pumpers had been using over 90% of the available water, and saw their *de facto* rights infringed without compensation or other incentive. They were thus the real stakeholders, rather than the 7,000 residents. Achieving the project goals required that the *de facto* rights of these 22 users be recognized. Incentives were created for them to manage the resource sustainably — but this meant that existing inequalities of access were reinforced. A World Bank official concluded about the Ta'iz project: "In our judgement, the 'egalitarian option' is not viable and ultimately counterproductive since it is unlikely to work" (Briscoe, 1999: 12).

3.3 Demand-management strategies

Potentially powerful indirect demand-management strategies exist that are not part of the current academic debate in the developing world. These offer important trade-offs that merit closer scrutiny. For example, it has been suggested that the problems of groundwater depletion in the Punjab, India could be eased if the region's export of 'virtual' groundwater — in the form of rice — could be reduced or stopped. Alternatively, using rainwater for rice cultivation may be an efficient way of recharging the aquifers, as argued by IWMI researchers. Especially as evaporation from rice fields is limited and, after the soils have been worked intensively, paddy fields provide ideal sites for recharge. Research into water-saving irrigation — such as alternate wet and dry irrigation (AWADI) used for rice in China — can also help save groundwater, although it needs to be examined whether these technologies would work as well in dry regions. There is also scope and need for more orderly development of groundwater for irrigation in areas where potential still exists, especially in South Asia and West Africa.

Another approach, the 'well-unit' regime, has been tried in China's Shanxi Province. It involves the coordinated construction of tubewells within a specific hydrogeological unit, matching the siting and total number of wells to groundwater potential. In the plains, such a unit typically covers 660 ha, and in mountainous regions 330 ha. The approach has the advantage of scientific siting of wells, unified management and optimal discharge of water, monitoring and maintenance of equipment and economies of scale on capital costs (FAO, 1994). In a large area of 94,800 ha in the Yinhuang irrigation district, conjunctive use of canal and groundwater has been tried with some success (FAO, 1994).

Tax-subsidy regimes have also been used to restrict withdrawals. For example, the over-developed Ogallala aquifer in Texas and Oklahoma supplies about 30% of all groundwater irrigation in the United States[7] (see <www.facingthefuture.org>). In this aquifer the rate of over-explotation declined — partly because of the increased costs of pumping and improved application efficiency, but also because of government programmes such as "Conservation Reserve" and "Payment-in-Kind" which offered added incentives to reduce cropping (Llamas et al., 1992).

3.3 *Artificial recharge: The state of the art*

Pro-active aquifer management is an established practice in many industrialized countries. For instance, the share of artificial groundwater recharge to total groundwater use is 30% in Germany, 25% in Switzerland, 22% in the United States, 22% in the Netherlands, 15% in Sweden and 12% in England (Li, 2001). In India, active aquifer management could involve planned draw-down of the water table in the pre-monsoon dry months as an important element of the strategy for enhancing recharge from monsoon rains, and from irrigation return flows. Although India has built more than its share of the world's dams, reservoirs can capture and store no more than a fifth of incident rainwater, according to standard reasoning. The bulk of the remainder runs off to the sea. However, groundwater levels could be significantly enhanced if even a fraction of India's annual loss of 1,150 km^3 of 'rejected recharge' (INCID, 1999) could be stored underground, reducing the velocity of the run-off and providing time for recharge.

Some experiments with artificial groundwater recharge outside Asia show successful approaches that have rescued valuable ecologies at risk. The Azraq Oasis in central Jordan is an example. Here, conventional measures to restore its ecology — such as rationing water supply to the city of Amman or giving up irrigation — were not politically feasible. However, a UNDP-supported project was able to reverse-pump 1.5 to 2 million m^3 of groundwater, imported from a water-surplus well field, into the epicenter of the Azraq lakes. Along with a number of supportive measures, such as cleaning of springs and rehabilitation, the strategy was able to revive the Azraq wetland almost to its original state. Birds came back and Azraq's tourism economy seemed to bounce back to life (Fariz and Hatough-Bouran, 1998).

Similar examples of interbasin transfer can be found, but only in developed countries.[8] However, these large-scale projects have held a wide appeal to Asian governments. China is already executing a mega project for trans-basin diversions of some 25 km^3/year from the Yangtze River in the water-rich south to the Yellow River basin in the water-short north (Keller et al., 2000). In India, there has been talk of a garland canal to link Himalayan rivers with the Cauveri and other South Indian rivers. These ideas have so far remained at the discussion level, but after each drought, these seemingly impractical ideas acquire new appeal and credibility.

In parts of India, recharge of aquifers is increasingly emerging as one of the best uses of surface irrigation structures. For example, it has been argued that the overall economics of the controversial Narmada project are rendered far more favourable by showing that Narmada waters will significantly counter groundwater depletion in North

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[7] One fifth, according to Postel (1999).

[8] One such example is the San Joaquin Valley of California, where groundwater irrigation was managed to create a tax base that would support import of water. With rapid agricultural growth, by the early 1950s, well irrigators were pumping more than 1.2 billion m^3 of water, and percolation of irrigation water became the main source of recharge, exceeding natural recharge by 40 times. The drawdown to 30–60 m caused a change in the direction of water flow in the confined zone; pumping lifts increased to 250 m in many parts; and land subsidence emerged as a widespread problem. These costs justified import of water through the California Aqueduct. After 1967, surface irrigation increased significantly, and hydraulic head declined by 30–100 m. 'Throughout the area, the recovery in potentiometer surface from 1967 to 1984 was nearly one half the drawdown that occurred from pre-development years to 1967. Increased recharge with surface irrigation and reduced groundwater draft raised water tables to less than 1.5 m in some parts causing drainage problems; a regional tile drain installed in 1988 over a 150 km^2 km area lowered the water table, but also diverted water that could have been used to increase recharge (Llama et al., 1992: 6–7).

Gujarat, where farmers are using subdizied electricity to lift groundwater from 250 to 300 m. The savings in electricity subsidy required to sustain groundwater irrigated agriculture and rural livelihood systems in water scarce regions, could tilt the benefit/cost ratios in favour of surface irrigation projects.

3.4 Home-grown solutions: Supply-side initiatives based on mass participation

The Asian response to groundwater depletion has been supply-side, rather than demand side. Long-distance transport of large quantities of water is not only expensive, but also problematic in other ways. Thus, in many parts of the world, especially in South Asia, *in situ* rainwater harvesting and recharge is being increasingly emphasized. In monsoon regions, this approach seems particularly useful because the bulk of the year's total rainfall is received within a short 100 hours of heavy downpour. Thus, there is little time for recharge of aquifers (Keller et al., 2000).

The relationship between the recharge area and rate and the extent of sustainable groundwater irrigation is now becoming increasingly important. A study of groundwater irrigation in Anuradhapura District in northern Sri Lanka shows that for every acre of groundwater irrigated area, 34 acres of recharge area is needed for sustainability in the uplands and 17 acres in the lowlands (Premanath and Liyanapatabendi, 1994). As the area under irrigation expands, land left for recharge shrinks, and recharge must be intensified.

Some water-scarce regions of Asia have age-old traditions and structures for rainwater harvesting. While these have unfortunately fallen into disuse, they are now attracting renewed attention. If estimates are to be believed, China has some 7 million ponds, which have potential for water harvesting and recharge.

In the South Indian states of Karnataka, Andhra Pradesh and Tamil Nadu, together possessing over 200,000 ponds (or tanks), the strategy of transforming these into recharge tanks by filling them up with canal water has been widely recommended (Kulandaivelu and Jayachandran, 1990; Reddy et al., 1990). In the Kurnool irrigation system of Andhra Pradesh, an experimental recharge project constructed nine percolation ponds and seven check dams, which had the effect of extending the duration of spring flow from 75 days to 207 days, and raising the post-monsoon water table by 2.5 m (Reddy et al., 1990). India's Central Groundwater Board has also been carrying out recharge experiments at several sites. IWMI has been studying the work of two local NGOs in the Alwar District of western Rajasthan, Tarun Bharat Sangh and Pradan. These NGOs have helped local communities to rehabilitate centuries-old tanks (known locally as *johads* or *paals*) over an area of 6,500 km^2, with dramatic impact on groundwater recharge and revival of dried-up springs and rivulets.

In southern India, where tanks are in a state of decline, wells are widely thought of as enemies of tanks. Before the 1960s, when modern tubewell technology became available to farmers, tanks were preserved, maintained and nurtured as valuable common-property irrigation structures. All those who benefited from a tank participated in its upkeep and the cleaning of its supply channels. During recent decades, better-off farmers have been able to increasingly privatize tank water by sinking tube wells close by. As a result, their stake in maintaining the tanks declined; and so did the age-old tradition of tank management.

In western India, the region hardest hit by groundwater depletion, however, well owners have championed the tanks because tanks keep the wells productive. Catalyzed first by spiritual Hindu organizations — such as the *Swadhyaya Pariwar* and *Swami Narayan Sampradaya* — and supported by numerous local NGOs, individuals and local communities have spontaneously created a mass movement for water harvesting and groundwater recharge. The underlying principle was that, "water on your roof, stays on your roof; water in your field stays in your field; and water in your village, stays in your village." Some 300,000 wells — open and bore — have been modified by local users to receive diverted rainwater. Also, thousands of ponds, check dams and other rainwater harvesting, and recharge structures have been constructed through self-help (Shah, 2000).

Systematic studies have not yet been made of the impact of the groundwater recharge movement in Gujarat, the popular science of rainwater harvesting, and decentralized recharge that have emerged as a result of farmers' experiments. However, indicative evidence suggests that in regions critically afflicted by groundwater depletion, only popular mass action on a regional scale appears adequate to remedy the situation (Shah and Desai, 2001).

India has begun to take rainwater harvesting and groundwater recharge seriously at all levels. These are at the heart of its massive Integrated Watershed Development Programme, which provides public resources to local communities for treatment of watershed catchment areas and for constructing rainwater harvesting and recharge structures. Trends during the 1990s also suggest a progressive shift of budgetary allocations from irrigation development to water harvesting and recharge. An indication of how seriously the Indian leadership views this issue is the message of the Prime Minister to the citizens on the Republic Day. Also, on 26 January 2001, India's Millennium Republic Day, the nation's Prime Minister and Water Resources Minister went to the people with a full-page story espousing the benefits and criticality of groundwater recharge.

Groundwater depletion has also revived popular interest in domestic rainwater harvesting techniques, both traditional and new. In water-stressed regions of countries like India, some of these techniques — evolved and used over centuries — are still preserved in far-flung areas. These techniques are now coming back in a big way, and include *Khadin*s of

Rajasthan; *tanka*s of western Gujarat, and a whole range of new roof harvesting techniques.

In the city of Rajkot in the water-scarce Saurashtra region of western India, 1500 new houses and apartments were built in 1997, incorporating a new design for rainwater harvesting and storage, modelled on old houses in the region — reviving a forgotten technique (Shah, 2000). Baluchistan and parts of Afghanistan have benefited from the excellent community service rendered by the extraordinary *karezes*, storing water for both domestic use and irrigation. Sadly, these are dying out, but should be revived and improvised upon.

Since time immemorial, Jordan and surrounding regions were honeycombed with family cisterns for rainwater harvesting for domestic use, a standard feature in dwellings. However, with the onset of modern piped-water supply, cisterns had fallen into disuse. The family cistern is now finding its way back (Wåhlin, 1997). In the United States, too, individuals and small groups are doing some exciting work to bring back traditional rainwater harvesting technologies. To support aquatic life for its biology laboratory, the University of Texas has built a system of three rainwater filled cascading ponds, somewhat similar to tank systems used in Tamil Nadu in South India. In the coastal desert of northern Chile, a fog collection project has been able to provide an average of 11,000 l/day of water to a community of 330 people (Schemenauer and Cereceda, 1991).

Many of the ideas discussed above may now appear before their time; but if water scarcity is growing at the rate recently projected by IWMI (Seckler et al., 1998), their time will surely come sooner rather than later.

4. Shifting gears: from resource development to management

In the business-as-usual scenario, problems of groundwater overexploitation will only become more acute, more widespread, serious and visible throughout Asia in years to come. Nevertheless, groundwater administration in Asia still operates in development mode, treating water availability as unlimited, and directing their energies towards enhancing production, despite the fact that symptoms of overexploitation are all too clear.

A major barrier to the transition from development to management of groundwater is lack of information. Many countries with severe groundwater depletion problems do not have any idea of the natural occurrence of the resource, nor of how much is withdrawn, where and by whom. Indeed, even in European countries where groundwater is important in all uses, there is limited systematic monitoring of its occurrence and withdrawal (Hernandez-Mora et al., 2001). Moreover, the amount and quality of science and management applied to national groundwater sectors is far less than what has been allocated to reservoirs and canal systems. This may be mainly because, unlike surface water, groundwater is in the private or informal sector, where public agencies play only an indirect role.

Gearing up for resource management entails at least four important steps:

1. Information gathering and resource planning by establishing appropriate systems for groundwater monitoring on a regular basis and undertaking systematic and scientific research on the occurrence, use and ways of augmenting and managing the resource;
2. Initiating some form of demand-side management through:
    a. Registration of users through a permit or license system;
    b. Appropriate laws and regulatory mechanisms;
    c. A system of pricing that aligns the incentives for groundwater use with the goal of sustainability;
    d. Promotion of conjunctive use;
    e. Promotion of precision irrigation and water-saving crop production technologies and approaches;
3. Initiating supply-side management through:
    a. Promoting mass-based rainwater harvesting and groundwater recharge programmes and activities;
    b. Maximizing surface-water use for recharge;
    c. Improving incentives for water conservation and artificial recharge; and finally;
4. Undertaking groundwater management at river basin level.

Groundwater interventions often tend to be too ‘local’ in their approach. Past and up-coming work at IWMI and elsewhere suggests that like surface water, groundwater, too, needs to be planned and managed for maximum basin-level efficiency. As groundwater becomes more scarce and more costly to use in relative terms, many ideas — such as trans-basin movement or using surface water systems exclusively for recharge — which in past years were discarded as not feasible or unattractive, can now offer new promise, provided, of course, that Asia learns intelligently from these ideas and adapts them appropriately to its unique situation.

In this article, we have offered a review of a variety of techno-institutional approaches that have been tried — and some which have worked, mostly in the industrialized world — but we conclude gloomily that transposing these lessons uncritically to the Asian context is destined to fail. In countries like the United States and Australia, characteristic features such as small numbers of large users and low population density create uniquely favourable conditions for certain institutional approaches. However, these do not work in Asia with its high population density and multitude of tiny users. For instance, a stringent groundwater law is enforced in Australia, but in Asia a similar law would be impossible to enforce due to prohibitive cost. Europe has a high population density, but it is much more comfortable in its overall water balance than is Asia. Moreover, at a high level of economic evolution, Europe can apply huge technological and financial muscle to manage its natural resources, something which South Asia and North China cannot do. Thus, for instance, per capita expenditure on groundwater management in the Netherlands is five times greater than total per capita income in rural northern Gujarat.

All in all, Asia's groundwater socio-ecology and resource management need a more refined approach suited to its genius, with a nuanced understanding of its peculiarities. In much of Asia, modern groundwater development has occurred in a chaotic, unregulated fashion, shaped by millions of tiny private users. Now, in many parts of Asia where groundwater is under the worst threat of depletion — such as western India, Baluchistan and North China — there is a groundswell of popular action — equally chaotic and unregulated — in rainwater harvesting and local groundwater recharge. At the frontline of this movement are regions like Rajasthan and Gujarat in India where untold havoc and misery could result if the groundwater bubble bursts. Here, rather than waiting for governments and high science to come to their rescue, ordinary people, communities, NGOs and religious movements have made groundwater recharge everybody's business. Many scientists and technocrats feel lukewarm about this grassroots movement, but chances are that at its heart lies the seed of decentralized local management of a critical natural resource.

Traditionally, people in Asia have treated water like manna from heaven and have seen no need to manage it. Now that they have begun to invest effort and resources in producing water, we see emerging the first inkling of community efforts to manage it. These popular recharge movements may offer the foundation on which Asia can build new regimes for sustainable groundwater management.

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