2 The Groundwater Economy of South Asia: An Assessment of Size, Significance and Socio-ecological Impacts

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Introduction

Groundwater has come to be the mainstay of irrigated agriculture in many parts of Asia, especially in populous South Asia and the North China Plain. Between them, India, Pakistan, Bangladesh and North China use over 380–400 km^3 of groundwater annually, over half of the world's total annual use. However, there are large variations in the patterns of Asian groundwater use. Groundwater irrigation is of little importance in South-east Asia and southern China, which have abundant surface water. On the other hand, nearly all of India, northern Sri Lanka, Pakistan Punjab and Sind, and the North China Plain represent regions where groundwater has come to play a unique and increasingly critical role in supporting a dynamic smallholder peasant agriculture. In fact, while the bulk of the rest of the world's groundwater use is urban and industrial, most South Asian groundwater use is in agriculture. The importance of groundwater to the agricultural economies of South Asia can easily be seen in figures from the region's two most populous countries. In India, some 60% of the irrigated areas are served by groundwater wells.[1] In Pakistan – which inherited the world's oldest and largest continuous system of canal irrigation 57 years ago and today serves some 16 million hectares in the Indus basin – it has been commonly thought so far that groundwater provides over 40% of the total crop water requirements in the highly populous province of Punjab, which produces 90% of the country's food (Qureshi and Barrett-Lennard, 1998). A 2001 International Water Management Institute (IWMI) survey of 180 farmers in Rechna Doab, however, showed that more than 70% of the farmers received 80–100% of their irrigation water from wells and tube wells (Shah *et al*., 2003).

Throughout South Asia, the history of protective well irrigation goes back to the millennia. However, intensive groundwater use on the scale we find today is a story of the last 50–nay, 30–years. In India, the total number of mechanized wells and tube wells rose from less than a million in 1960 to an estimated 19 million in

2000. In Pakistan Punjab, it increased from barely a few thousands in 1960 to 0.5 million in 2000. In Bangladesh, which hardly had any groundwater irrigation until 1960, the area irrigated by groundwater wells shot up from 4% in 1972 to 70% in 1999 (Mainuddin, 2002).

Hydrogeology and Resource Availability

This explosive growth in groundwater irrigation has had little relationship with the pattern of occurrence of the groundwater resource. Figure 2.1 presents the first ever groundwater recharge map of the world prepared by researchers at the University of Kassel (Germany). It shows that in terms of long-term groundwater recharge, South Asia and the North China Plain are less well endowed compared to South America, pockets of sub-Saharan Africa and South-east Asia.

Many scientists argue that in the long run, groundwater development is self-regulating; people cannot pump more water than there is in the aquifers. According to them, long before the hydrogeology of aquifers imposes a check on further development, the economics of pumping water from deep aquifers would do so.[2] It is therefore ironic that global pockets of intensive groundwater use have emerged in regions that are not amongst the best endowed for it. Many of these regions have alluvial aquifers of high quality. The entire Indo-Gangetic plain that encompasses Pakistan Punjab and Sind, all of Northern India, Nepal Terai and Bangladesh are examples; so are areas of the North China Plain. However, all these are arid or semiarid, receiving little rainfall to provide natural recharge. Two-thirds of India (nearly half of the Indian subcontinent), in contrast, is doubly disadvantaged: it has semiarid climate with limited rainfall for recharging the aquifers; and hard-rock, basaltic aquifers with low storativity values. Peninsular India therefore is amongst the worst candidates for intensive groundwater irrigation; and yet, this is the region that has followed the Indo-Gangetic plain in ushering in a tube well revolution.

This paradox is global. High levels of sunlight combined with frequently lower levels of pest and disease problems can create optimal conditions for intensive agriculture – as in California, Spain and Israel. In contrast, many humid regions do not have as intensive agriculture despite – or perhaps because of – abundant water from groundwater or other sources (M. Moench, 2005, e-mail communication). In arid areas without resources for recharge, however, stringent limits to intensive groundwater irrigation are accessed early, leading to severe depletion, and at times, corrective measures as in Israel (which achieved high agricultural water productivity) and Saudi Arabia (which for some time had a vibrant wheat economy based on irrigation with fossil groundwater that has been progressively shrunk (Abderrahman, 2003)).

With this backdrop in mind, Fig. 2.2 attempts to highlight the irony of Asia's groundwater boom in the last 50 years. It is a common knowledge that hydrogeologic features of a terrain vary greatly even within a square mile, especially in hard-rock aquifers. So the classificatory approach we have used in Fig. 2.2 oversimplifies the great hydrogeologic diversity found in Asia, and can be justified only from the viewpoint of understanding aggregate patterns at a sub-

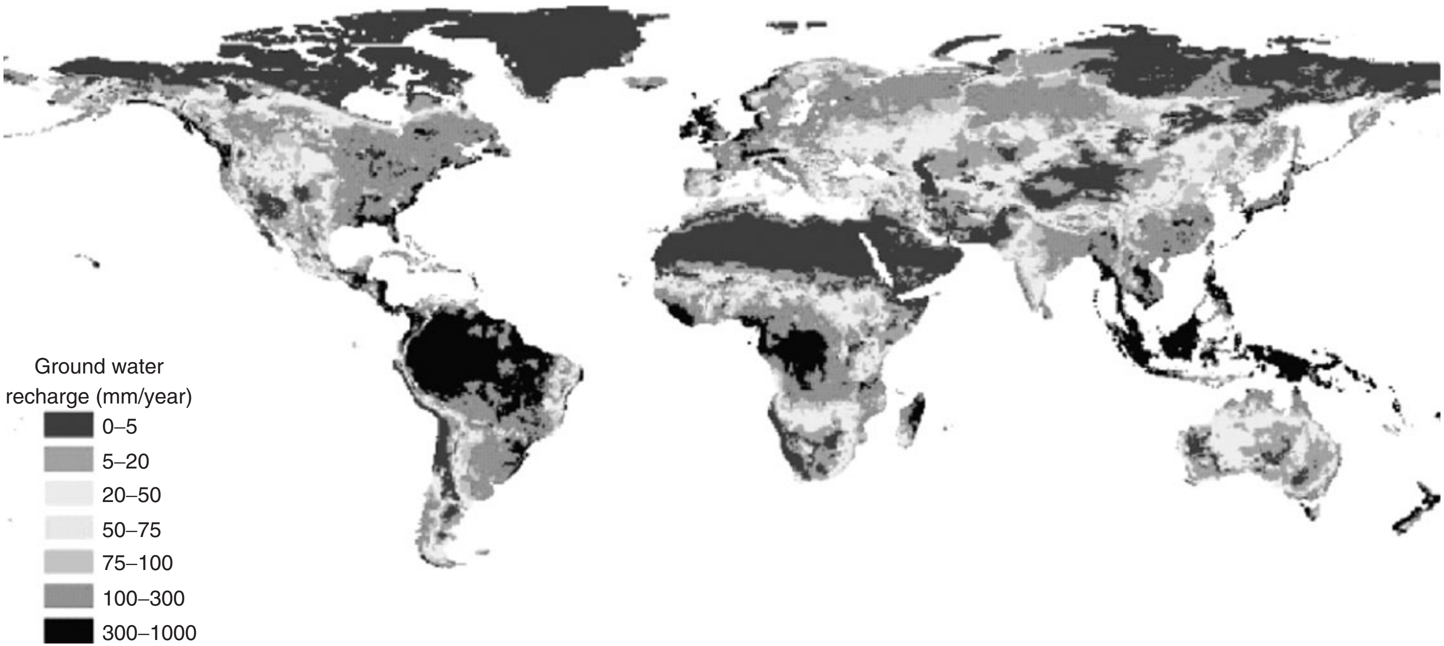


Fig. 2.1. Long-term average groundwater recharge. (Döll *et al.* 2002.)

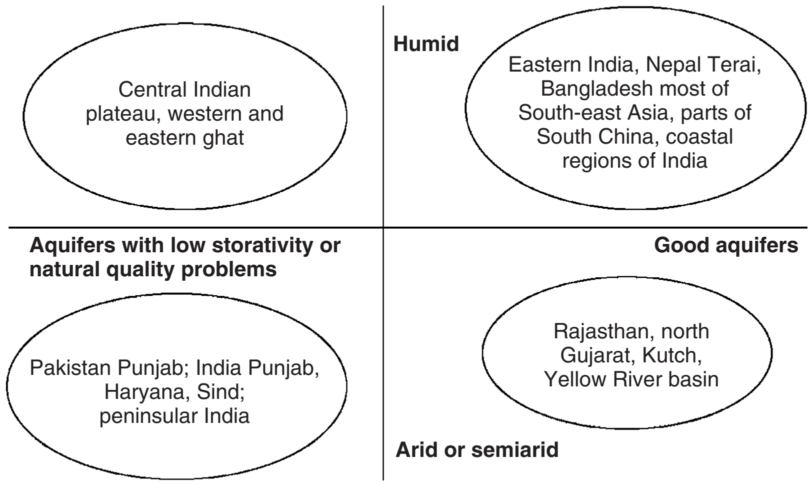


Fig. 2.2. Hydrogeologic patterns in Asia.

continental level. Regions best suited for this boom are those with high rainfall and good aquifers (North-West quadrant); however, except for Bangladesh and parts of eastern India, the groundwater boom has left these regions untouched. The groundwater irrigation economy is insignificant in South China and much of South-east Asia, which can sustain much more intensive groundwater irrigation than they currently practise. In contrast, it has assumed boom proportions in all the other three quadrants, none of which has 'appropriate' hydrogeologic and climatic conditions for intensive groundwater irrigation.

Around the world, intensive groundwater development without appropriate resource management regimes has resulted in resource degradation. In South Asia, this threat is growing. Besides non-point pollution of groundwater through chemical fertilizers and pesticides, intensive use of groundwater in agriculture gives rise to four resource management challenges: (i) controlling resource depletion; (ii) optimal management of conjunctive use of surface and groundwaters; (iii) managing the productivity impacts of secondary salinization; and (iv) managing natural groundwater quality concerns. The seriousness of each of these varies across regions depending upon their hydrogeology and the degree of groundwater development as set out in Fig. 2.3. It is clear that even in upper-right quadrant regions, which provide robust hydrogeologic platforms for intensive groundwater irrigation, socio-ecological and public health problems need to be managed as groundwater irrigation expands. In the eastern Gangetic basin, for instance, groundwater development is associated with mobilization of (geogenic) arsenic. Coastal areas are typically humid and have good alluvial aquifers; but salinity ingress or sea-water intrusion into coastal aquifers is a common problem, sometimes even at early stages of groundwater development. Likewise, in all humid areas (or arid areas with large volumes of surface water movement) with intensive groundwater irrigation, conjunctive management of surface and groundwaters remains a major challenge as well as an opportunity.

Hydro-geological Settings		Socio-economic and Management Challenges			
		Resource Depletion[a]	Optimizing conjunctive use[b]	Secondary salinization[c]	Natural Groundwater Quality Concerns
Major alluvial plants	Arid	●●	●○	●●●	●
	Humid	●	●●●		●●
Coastal plains		●●	●	●●○	●
Inter-Montane valleys		●	●●	○	●
Hard-rock areas		●●	○	●	●●●

[a]Related to aquifer recharge rates and storate availability.
[b]Implies both abundant surface and groundwater availability.
[c]Implies limited fresh groundwater availability and presence of saline groundwater and/or land drainage problems.

Fig. 2.3. Resource management challenges of intensive groundwater use in Asian agriculture.

As mentioned earlier, the geology of central and peninsular India is different and far more complex compared with that of the Indo-Gangetic basin, which consists of extensive alluvial aquifers throughout. Figure 2.4, showing a map of major aquifers of India by the Central Ground Water Board, suggests the dominance of basalt and crystalline rock formation in peninsular India. The water-bearing and -conveying properties of these aquifers vary greatly even over small distances, making scientific resource management critical and difficult at the same time (GoI, 1995). Overall, however, the yields of these aquifers are quite modest and, in fact, much smaller than much of sub-Saharan Africa; yet, there is a heavy and growing dependence on groundwater irrigation even in these regions.

Scale and Significance of South Asia's Groundwater Economy

Historical underpinnings

Rapid growth in groundwater use is a central aspect of the world's water story, especially since 1950. Shallow wells and muscle-driven lifting devices have been in vogue in many parts of the world for millennia. In British India (which includes India, Pakistan and Bangladesh), these accounted for over 30% of irrigated land even in 1903 (http://dsal.uchicago.edu/statistics/1894_excel) when only 14% of cropped area was irrigated. With the rise of the tube well technology and modern pumps, groundwater use soared to previously unthinkable levels after 1950; as a result, by the mid-1990s, groundwater-irrigated areas in

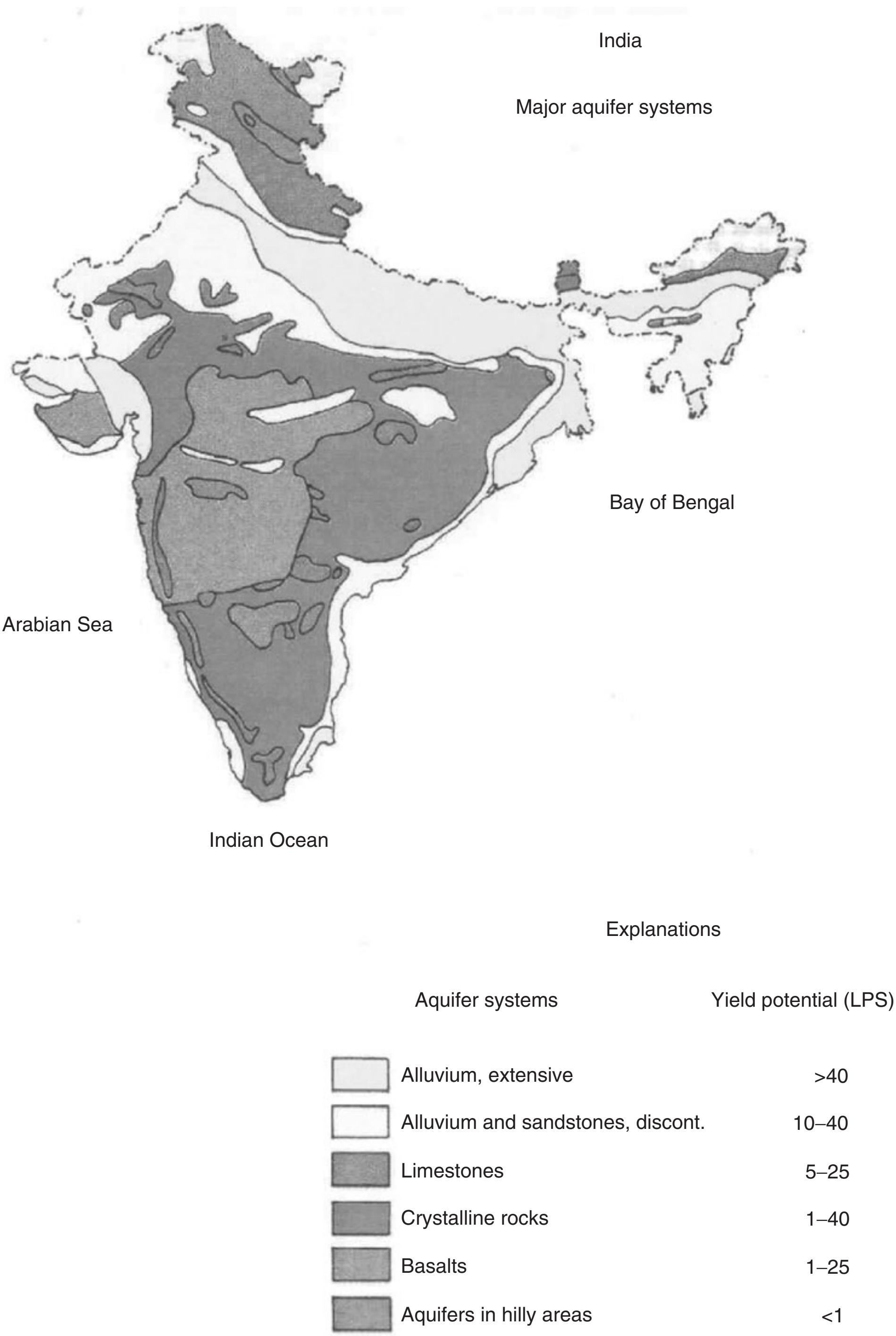


Fig. 2.4. Major aquifer systems of India. (From CGWB, 1995, p. 145.)

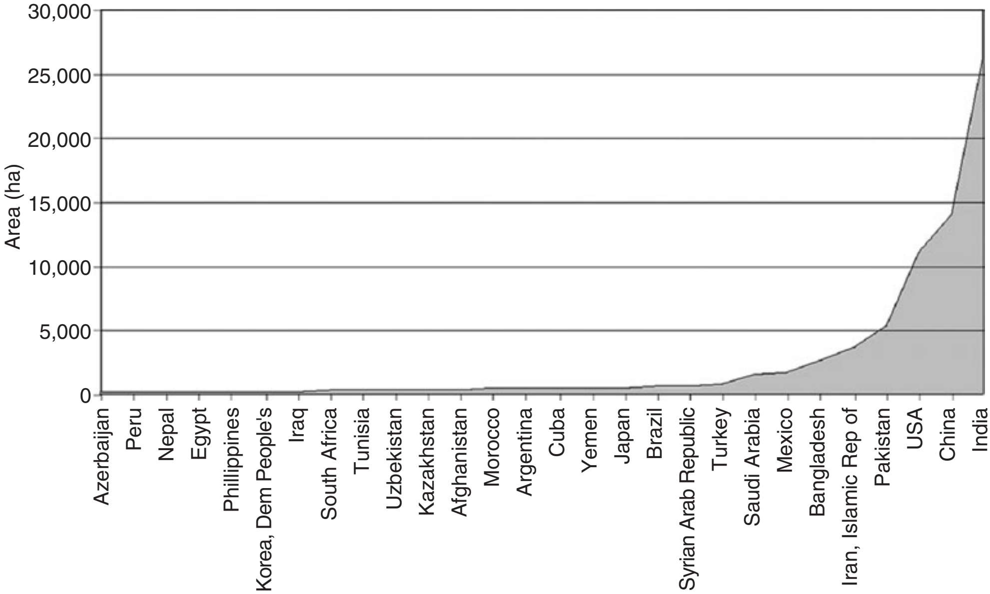


Fig. 2.5. Groundwater-irrigated area in countries with intensive groundwater use in agriculture. (From Food and Agricultural Organization, 2003.)

India, Pakistan and Bangladesh together were much larger than anywhere else in the world (Fig. 2.5). Indeed, one might surmise that of the 270–300 million hectares of global irrigation economy, more than one-third – around 110 million hectares – likely comprises groundwater-irrigated areas in the Indian subcontinent alone. Other groundwater economies of the world seem small by South Asian standards. In Spain, groundwater use increased from 2 km^3/year in 1960 to 6 km^3/year in 2000 before it stabilized (Martinez-Cortina and Hernandez-Mora, 2003). In western USA, which is larger in geographic area than the Indian subcontinent, although growth in total agricultural water use has tapered off, groundwater's share in irrigation has increased from 23% in 1950 to 42% in 2000, and has stabilized at around 107 km^3 (http://water.usgs.gov/pubs/circ/2004/circ1268/). In the Indian subcontinent, groundwater use soared from around 10–12 km^3 before 1950 to 240–260 km^3 in 2000 (Shah, 2005). Despite its growing pre-eminence, data on groundwater use are hard to find; however, Fig. 2.6 uses patchy data available from several countries to backcast the probable trajectories of growth in groundwater use in selected countries. While in the USA, Spain, Mexico, and African countries like Morocco and Tunisia total groundwater use peaked during the 1980s, in South Asia and the North China Plain, the upward trend began during the 1970s and is still growing (see Wang *et al*., Chapter 3, this volume).

The striking aspect of South Asia's (and China's) groundwater boom is that it has acquired its present prominence only after 1970. Figure 2.7 shows the growth in the number of irrigation pumps in India during 1951–1993 and projects these to 2005. Figure 2.8 shows the corresponding change in the relative

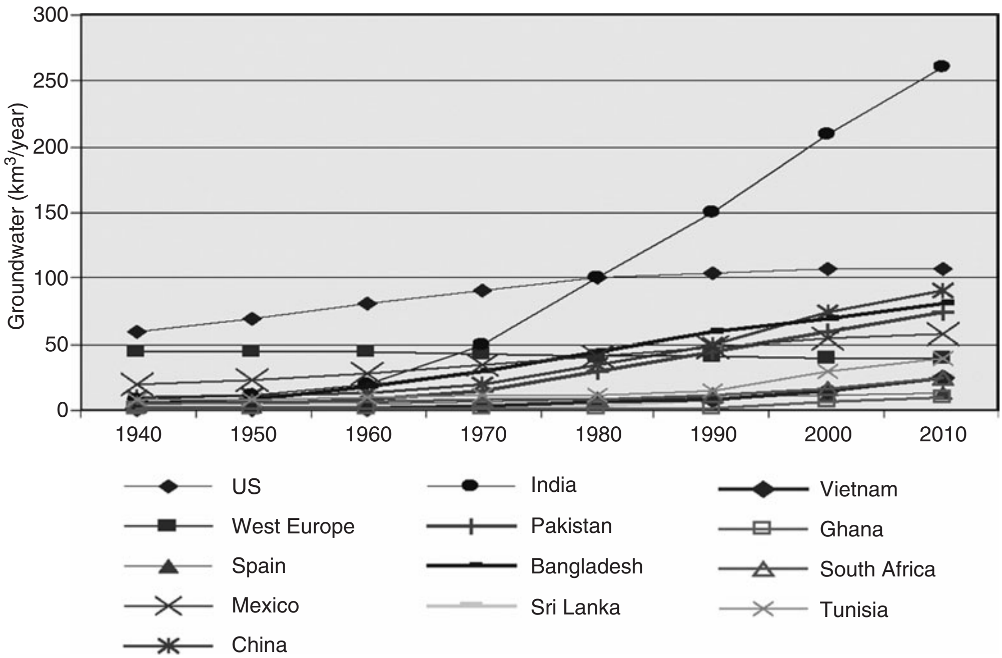


Fig. 2.6. Growth in groundwater use in selected countries. (From authors' estimates.)

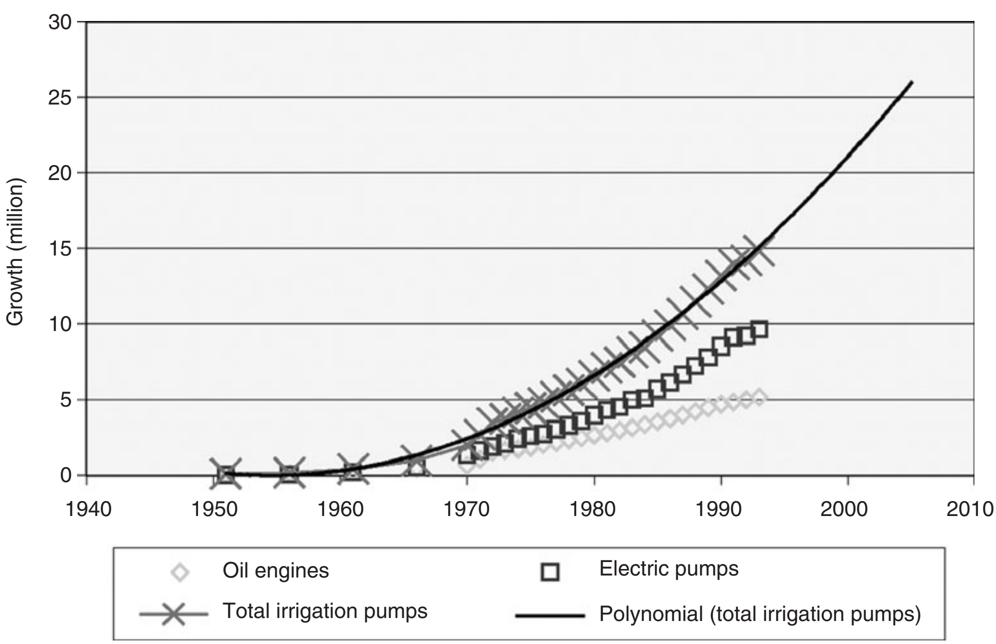


Fig. 2.7. Growth of irrigation pumps in India. (From World Bank and Ministry of Water Resources, 1998.)

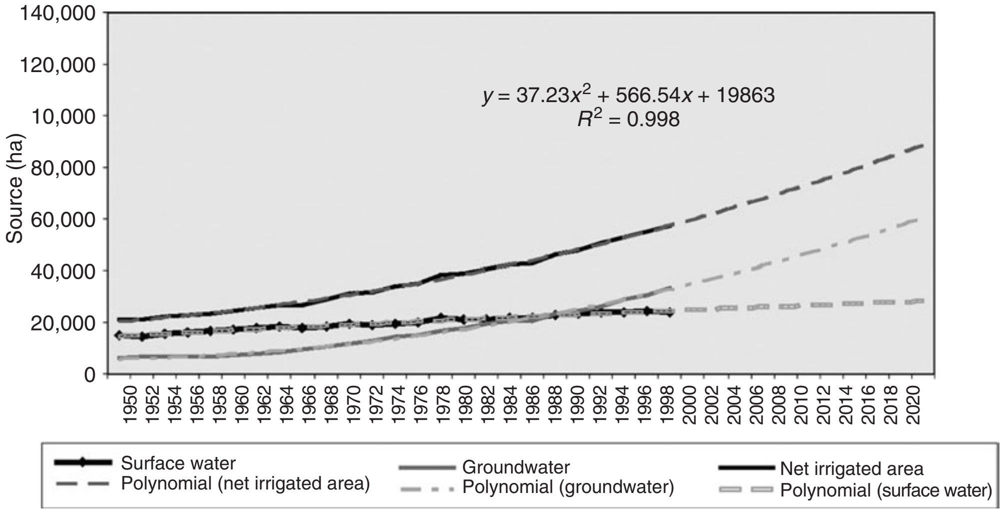


Fig. 2.8. Changing share of different sources in India's irrigated area: 1951–1998–2020.

share of different sources of irrigation in total irrigated area in India, indicating clearly that groundwater wells that irrigated just around 10 million hectares in 1970 are now serving over 35 million hectares of net irrigated area in India. Surface irrigation sources – tanks and canals – that had dominated irrigated agriculture in India for decades now gave way to groundwater irrigation. How did this role reversal affect the economics of South Asian agriculture?

Socio-economic significance

In these predominantly agrarian regions of South Asia, the booming groundwater economies have assumed growing significance from viewpoints of livelihood and food security; however, their significance as engines of rural and regional economic growth has remained understudied. There are several ways to consider the scale of the groundwater economy; but one practical measure is the economic value of the groundwater production. An unpublished report for the United States Agency for International Development (USAID) in the early 1990s placed the contribution of groundwater irrigation to India's gross domestic product (GDP) at around 10% (Daines and Pawar, 1987); if the same proportion holds now, the size of the groundwater irrigation economy of India would be approximately $50–55 billion. In Table 2.1, we attempt a rough estimation of the market value of groundwater use in the Indian subcontinent. India, Pakistan and Bangladesh have active markets in pump irrigation service in which tube well owners sell groundwater irrigation to their neighbours at a price that exceeds their marginal cost of pumping. This price offers a market valuation of groundwater use in irrigation. We have used available estimates of the number of irrigation wells and estimates from sample surveys on average yield of wells and annual hours of operation of irrigation tube wells in the

Table 2.1. Proximate size of the agricultural groundwater economy of South Asia and the North China Plain (2002).

		India	Pakistan Punjab	Bangladesh	Nepal Terai
A	Number of wells (million)	21	0.5	0.8	0.06
B	Average output/well (m^3/h)	25–27	100	30	30
C	Average hours of operation/ well/year	360	1090	1300	205
D	Price of pump irrigation ($/h)	1–1.1	2	1.5	1.5
E	Groundwater used (km^3)	189–204	54.5	31.2	0.37
F	Value of groundwater used per year in billion dollars	7.6–8.3	1.1	1.6	0.02

countries covered. In India, for instance, a large number of farmers paid their neighbouring bore well owners $0.04/$m^3$ for purchased groundwater irrigation in around 2000[3]; applying this price to the annual groundwater use of say 200 billion cubic metres gives us $8 billion as the economic value of groundwater used in Indian agriculture per year. For the Indian subcontinent as a whole, the corresponding estimate is around $10 billion. In many parts of water-scarce India, water buyers commonly enter into pump irrigation contracts offering as much as one-third of their crop share to the irrigation service provider; in water-abundant areas, in contrast, purchased pump irrigation cost amounts generally to 15–18% of the gross value of the output it supports. This can be used to draw the general inference that the agricultural output that groundwater irrigation supports is 4–5 times its market value.

Impact on agricultural growth: the case of India

Table 2.2 provides a synopsis of more detailed evidence of the size of India's groundwater economy, which is more explicitly described in DebRoy and Shah (2003).[4] In short, a regression equation was fit to cross-section data for 273 districts in which the dependent variable was the average value of gross farm output per hectare; and independent variables were average fertilizer use per hectare, percent of net sown area under surface irrigation and percent of net sown area under groundwater irrigation. Regressions were estimated for 1970–1973 and 1990–1993 data-sets. These showed that adding a hectare under groundwater irrigation made smaller contribution to increasing average value of output per hectare compared with adding a hectare under canal irrigation because farmers in South Asian canal commands are doubly blessed: they use cheap canal water to cut irrigation costs and costly groundwater to give their crops 'irrigation-on-demand'. However, the increase in groundwater irrigated area in an average Indian district after 1970 has been so large that groundwater irrigation contributed much more to increased value of agricultural output per hectare compared with surface irrigation. Table 2.3 summarizes the results; it shows that in the scenario of growing productivity of farmland, the contribution of surface

Table 2.2. Contribution of surface water irrigated and ground water irrigated area to total agricultural output, all India: 1970–1973 and 1990–1993. (From DebRoy and Shah, 2003.)

Year/indicators (at 1990 dollar/rupee exchange rate)	1970–1973	1990–1993	Change (%)
Average agricultural productivity ($/ha)	261.4	470.3	79.9
Contribution of SW ($/ha)	41.3	62.6	51.6
Contribution of GW ($/ha)	13.3	74.0	456.4
Contribution of SW (million $)	4,680	7,005	49.7
Contribution of GW (million $)	1,320	7,297	452.8
Contribution of SW as percent of total agricultural output	15.5	13.9	−1.6% points
Contribution of GW as percent of total agricultural output	4.4	14.5	+10.1% points
Total agricultural output/year (million $)	28,282	49,891	76.4

Table 2.3. Groundwater use per hectare in South Asia. (From IWMI survey of 2629 farmers in 2002.)

	Horse power hours	Total crop water requirements (m^3)*	Estimated average application of irrigation water by sample farmers
Wheat	656	4,000	1,476.00 (36.9)
Kharif paddy	1,633	12,000	3,674.25 (30.6)
Boro paddy	3,266	18,000	7,348.50 (40.8)
Oilseeds	816	5,500	1,836.00 (33.4)
Coarse cereals	811	5,000	1,824.75 (36.5)

*Michael 2001

irrigation to aggregate farm output increased by 50% over 1973–1993, but that of groundwater irrigation soared by 450% over the same period. Interestingly, at $7.3 billion, groundwater contribution to agricultural output is close to $8 billion, which is our rough estimate of the economic value of groundwater irrigation in India in Table 2.2. To place this number in perspective, it is useful to note that this contribution of groundwater development to annual farm output in India is four times the annual public investment in irrigation projects, and more than all expenditures incurred by governments in India on poverty alleviation and rural development programmes.

Population pressure as the driver of tube well density

When the colonial government began building large run-of-the-river irrigation systems in northern and North-western India (which included the present Pakistan) in the early 19th century, these led to the decline in the tradition of well irrigation in Uttar Pradesh but stimulated it in North-western India.

During the latter half of the 20th century, these canal-irrigated areas led the charge in creating South Asia's groundwater boom, resulting in a widely held belief that large-scale tube well irrigation development occurs only in canal-irrigated areas. There was a time perhaps when this was largely true; however, the groundwater reality of South Asia has transcended this stage. In fact, as Figs 2.7 and 2.8 show, the density of tube wells – and groundwater irrigation in India and Pakistan Punjab – seems to have less to do with availability of surface water for recharge than with population pressure on agriculture. The figures show that tube well density is high throughout the Gangetic basin in India, which does have high groundwater availability but also very high population density. However, tube well density in Pakistan Punjab is highest in the most densely populated districts (Qureshi *et al*., 2003). It is also high in many other parts of India such as Tamilnadu, Andhra Pradesh and Karnataka where water resources are limited but population density is high. On the other hand, in many parts of central India, little of the available resource is developed; yet tube well density is low because these regions are sparsely populated (DebRoy and Shah, 2003). China too has a similar pattern: groundwater development is low in South China, which has abundant surface water and low population density (except in the eastern coastal region); but tube well densities are high in the North China Plain, which has low surface water resource and high population density. Compared to large public irrigation projects that are driven by hydrologic opportunity, groundwater development is democratic, providing irrigation wherever people are.

Regional equity and drought-proofing

This pattern of groundwater development has brought much succour to the rural economy of the region. Without groundwater development, agriculture would have stagnated or declined in peninsular and eastern India and Bangladesh; food security would of course be endangered; but a more critical problem would be supporting rural livelihood during the decades these regions would take to transfer a sufficient proportion of their agrarian populations to off-farm livelihood systems. South Asia emerged out of British rule with a pattern of irrigation development that showed high regional inequality. The colonial government of India invested in large irrigation projects as a response to recurring famines that caused millions of starvation deaths; but these investments were concentrated in the North-western parts of British India and the Cauvery delta in the South while irrigation development in central and eastern regions was neglected (Whitcombe, 1984; Roy 2004). In the post-colonial era, too, public investments in canal irrigation projects were concentrated in pockets, leaving the rest of the region to rain-fed farming. In contrast, the development of groundwater irrigation had a significant 'equalizing effect'. It also emerged as the biggest drought-mitigator; during the 1960s, a major drought reduced India's food production by 30–40%, forcing India into embarrassing 'ship-to-mouth' dependence on US PL 480 wheat. Since the 1990s, food production has hardly been affected by a single drought (Sharma and Mehta, 2002), though a string of 2–3 drought years can still have an impact. Groundwater development has thus been a major restorer of India's national pride and confidence in feeding its people, and it has helped Bangladesh to transform from an endemic rice importer into a rice exporter (Palmer-Jones, 1999). Throughout the region, the easing of the obsessive sense of insecurity about national food self-sufficiency is explained in no small measure by the development of groundwater irrigation.

Supplemental nature of groundwater irrigation in South Asia

In order to better understand the nature of groundwater irrigation in South Asia, IWMI, in collaboration with several partners, undertook a large-scale survey of 2600 well owners from 300 villages selected to represent all regions of India, Pakistan, Bangladesh and 20 districts of Nepal Terai (see DebRoy and Shah, 2003, and Shah *et al*., 2006, for details of the survey design and results). One of the aims was to find out if intensive groundwater irrigation occurs in regions with large-scale canal irrigation. Figure 2.9, which summarizes the results, shows that almost everywhere in the subcontinent, groundwater contribution to irrigated areas exceeds that of surface water; that outside of Pakistan Punjab and Sind, conjunctive use of surface and groundwaters at the farmer level is small; that in North-western India, despite massive investments in canal irrigation, the bulk of the irrigation is delivered by wells and tube wells. Figure 2.10, again based on the IWMI survey, suggests that thanks to the groundwater revolution, rain-fed regions, districts or even villages are rare in South Asia; there are just rain-fed and irrigated plots. Just around 5% of the 278 villages covered reported completely rain-fed agriculture; nearly half of the villages had groundwater-dominated irrigated agriculture; pure canal irrigation (i.e. with no wells or tube wells) accounted for just 10% of the villages and 20% of the irrigated area in the sample.

Another key feature of groundwater irrigation in South Asia is its predominantly supplemental nature. The IWMI survey of 2002 collected information from 2629 sample farmers about the depth of pumping water level, hours pumped for different crops and the capacity of pumps. Using these data, rough estimates were made of the actual average application of irrigation water for key crops. When these are compared with CROPWAT recommendations, we find that farmers provide around one-third of the crop-water requirements through groundwater.

Other studies show that such supplemental groundwater irrigation is also significantly more productive compared with surface irrigation, because it offers individual farmer irrigation 'on demand' which few surface systems can offer; and because its use entails significant incremental cost of lift, farmers tend to economize on its use and maximize application efficiency. Evidence in India suggests that crop yield per cubic metre of water applied on groundwater-irrigated farms tends to be 1.2–3 times higher than that applied on surface water–irrigated farms (Dhawan, 1989, p. 167).[5] In terms of return on investment, groundwater irrigation in South Asia has done very well. In Pakistan Punjab, capital investment in private tube wells is estimated to be of the order of Pak Rs. 25 billion[6] ($0.4 billion at 2001 prices), whereas, according to one

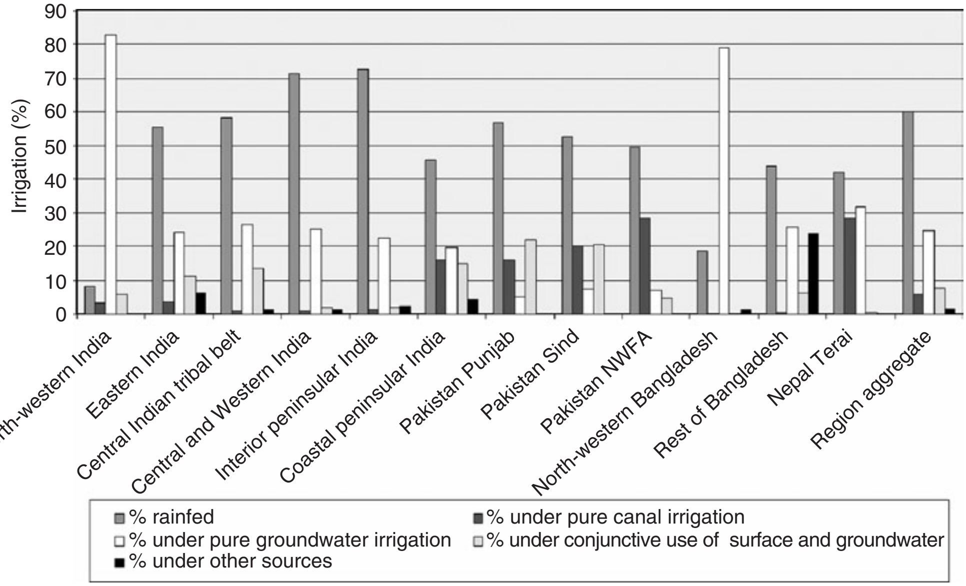


Fig. 2.9. Sources of irrigation in different hydro-economic zones of South Asia. (From IWMI–Tata Survey.)

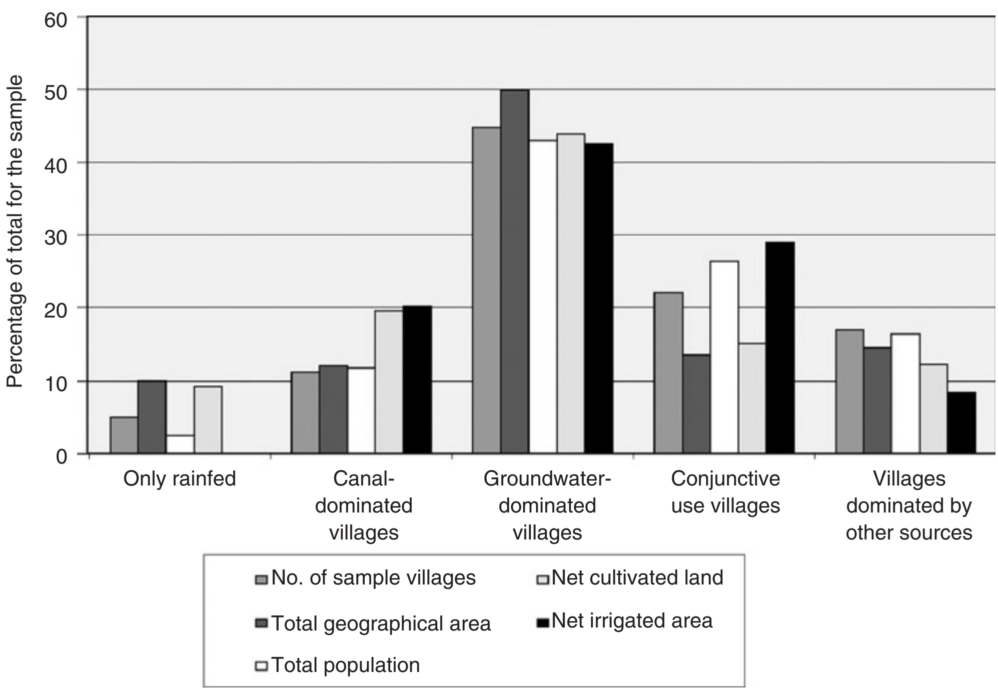


Fig. 2.10. Relative importance of wells, canals and other sources of irrigation in sample villages. (From IWMI–Tata Survey.)

Table 2.4. Comparison of farms with and without tube well water supply, Pakistan. (From Ministry of Agriculture, 1988.)

Item	Unit	Type	Sugarcane	Rice	Cotton	Wheat
Cropped area	Percent farm area	With TW	8	13	8	60
		Without TW	3	3	7.5	50
Yield per acre	Tonnes	With TW	23.6	1.3	0.40	1.10
		Without TW	12.6	0.9	0.38	0.76
Gross value per acre	Pak Rs.[a]	With TW	23,800	14,188	8,624	56,808
		Without TW	4,725	2,910	5,060	33,300

[a]$1 = Pak Rs. 65 in September 2001.
TW = Tube wells.

estimate, the annual benefits in the form of agricultural production of the order of Pak Rs.150 billion ($2.3 billion) accrue to over 2.5 million farmers, who either own tube wells or hire the services of tube wells from their neighbours. The best farm level productivity performance of course is obtained by those who can use a judicious combination of surface and groundwater. Table 2.4 reports physical and value productivity on 521 canal-irrigated farms in the Indus system in Pakistan Punjab and shows that farmers with wells obtain 50–100% higher yield per acre and 80% higher value of output per acre compared with canal irrigators without wells. Groundwater users in South Asia often use only a small fraction of scientifically recommended water requirements; rather than aiming at fully irrigated yields, they use sparse, life-saving irrigation to obtain substantial increases over rain-fed yields (see Fig. 2.11). This is because of the high marginal cost of groundwater use; some of the poorest irrigators in arid parts of South Asia – who purchase pump irrigation from well owners – commonly pay 10–14 cents/m^3 of water compared to a fraction of a cent paid by canal

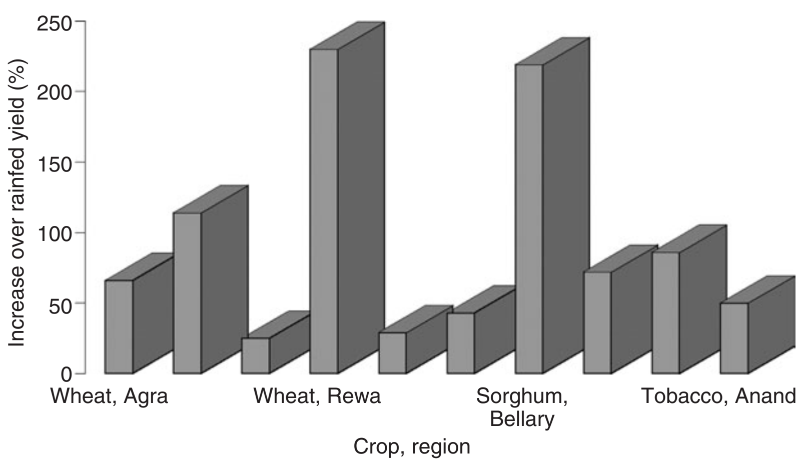


Fig. 2.11. Yield impact of life-saving 5 cm irrigation on rainfed crops in India. (From Dhawan, 1989, after Singh and Vijaylakshmi, 1987.)

irrigators. Finally, compared to large surface systems whose design is driven by topography and hydraulics, groundwater development is often much more amenable to poverty targeting. No wonder, then, that in developing regions of South Asia, groundwater development has become the central element of livelihood creation programmes for the poor (Kahnert and Levine, 1993, for the GBM basin; Shah, 1993, for India; Calow *et al.*, 1997, for Africa).

Socio-economic vs. socio-ecological impacts

All in all, as a purely socio-economic phenomenon, South Asia's groundwater irrigation boom has been an unalloyed success. By all accounts, it has served the purpose of a massive programme of strengthening rural livelihood. It has made the region food-secure at macro-level. It has done more to alleviate rural poverty than most public interventions expressly designed to that end. In scale and depth, its socio-economic impacts are comparable to some of the world's most successful development programmes such as the dairy cooperative movement of India that revolutionized India's dairy economy.

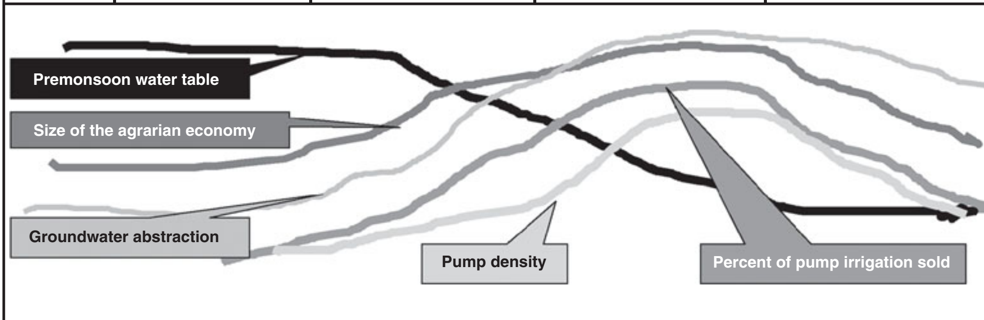
However, overall socio-ecological returns to the boom have long since been declining on the margin. In many regions, groundwater depletion that manifests in secular decline in water tables is beginning to take its toll. Pumping costs are rising; well failures and abandonment are evermore frequent. All the resource management challenges we outlined in Fig. 2.3 are in full play; and there are few regions left apart from pockets of the eastern Gangetic basin, where further groundwater development can be had more or less as a 'free lunch'.

The Pathology of Decline of a Groundwater Socio-ecology

A few years ago, David Seckler, the then director general of IWMI, wrote alarmingly that a quarter of India's food harvest is at risk if she fails to manage her groundwater properly. Many people today think that Seckler might have well underestimated the situation, and that if India does not take charge of her groundwater, her agricultural economy may crash. Postel (1999) has suggested that approximately 10% of the world's food production depends on overdraft of groundwater to the extent of 200 km^3; most likely, 100 km^3 out of this occurs in western India. In the lower Indus basin in Pakistan and the Bhakra system in northern India, groundwater depletion is not a problem but soil and groundwater salinization is. IWMI's past research to understand 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 four-stage progression outlined in Fig. 2.12. This highlights the typical progression of a socio-ecology from a stage in which unutilized groundwater resource potential becomes the instrument of unleashing an agrarian boom to one in which, unable to apply brakes in time, it goes overboard in exploiting its groundwater.

The four-stage framework outlined in Figure 2.12 shows the transition that South Asian policymakers and managers need to make from a resource

	Stage 1	Stage 2	Stage 3	Stage 4
Stages	The rise of Green Revolution and tube well technologies	Groundwater-based agrarian boom	Early symptoms of groundwater overdraft and degradation	Decline of the groundwater socio-ecology with immiserizing impacts



Examples	North Bengal, North Bihar, Nepal Terai, Orissa	Eastern Uttar Pradesh, western Godavari, central and South Gujarat	Haryana, Punjab, western Uttar Pradesh, central Tamilnadu	North Gujarat, coastal Tamilnadu, 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 tube wells; 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 groundwater use part ways	The 'bubble' bursts; agricultural growth declines; 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 tube well 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 irrigations emerge as a huge, powerful vote bank that political leaders cannot ignore	Subsidies, credit and donor support reluctantly go; NGOs and 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 actions start

Fig. 2.12. Rise and fall of groundwater socio-ecologies in South Asia where economies follow a four-stage progression.

development mindset to a resource *management* mode. Forty years of Green Revolution and mechanized tube well technology have nudged many regions of South Asia into stages 2–4. However, even today, there are pockets that exhibit characteristics of stage 1, but the areas of South Asia that are at stage 1 or 2 are shrinking by the day. Many parts of western India were in this stage in the 1950s or earlier, but have advanced into stage 3 or 4. An oft-cited case is North Gujarat where groundwater depletion has set off a long-term decline in the booming agrarian economy; here, the well-off farmers who foresaw the impending doom forged a generational response and made a planned transition to a non-farm, urban livelihood. The resource-poor have been left behind to pick up the pieces of what was a booming economy barely a decade ago. This drama is being re-enacted in ecology after groundwater socio-ecology with frightful regularity (Shah, 1993; Moench, 1994; Barry and Issoufaly, 2002).

In stage 1 and early stage 2, the prime concern is to promote profitable use of a valuable, renewable resource for generating wealth and economic surplus; however, already by stage 2, the thinking needs to change towards careful management of the resource. Yet, the policy regime ideal for stages 1 and 2 has tended to become 'sticky' and to persist long after a region moves into stage 3 or even 4. IWMI's recent work in the North China Plain suggests that the story is much the same over there. The critical issue to address is: Does stage 4 always have to play out the way it has in the past? Or are there adaptive policy and management responses in stage 2 that can generate a steady-state equilibrium, which sustains the groundwater-induced agrarian boom without degrading the resource itself? In the remainder of this chapter, we review the prospects and opportunities for forging such steady-state equilibrium.

In Search of Sustainability

Challenge of demand-side management

The South Asian debate on creating effective groundwater management regimes has been swayed by the success stories of groundwater regulation in Australia and the USA where the number of users is small, and their average size very large (see Table 2.5); or from Europe, which has a large number of small users but where the state has capacity to deploy huge financial and technological resources to mend its natural resources problems. The South Asian situation is different; as a result, the debate continues but the policy alternatives commended come unstuck. Enacting and enforcing a groundwater law, establishing clear tradable property rights on water, pricing groundwater as an economic good, installing and enforcing a licensing and permit system have all been discussed *ad nauseum* in South Asia as desirable policy interventions to regulate groundwater overdraft (see e.g. Arriens *et al.*, 1996, pp. 176–178,

Table 2.5. Structure of national groundwater economies of selected countries.

Country	Annual groundwater use (km^3)	No of agricultural groundwater structures (million)	Extraction/ structure (m^3/year)	Percent of population directly or indirectly dependent on groundwater irrigation
India	150	19	7,900	55–60
Pakistan Punjab	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

239–245). Nobody seems to disagree with the need for these; yet, no Asian country has been able to deploy any of these interventions effectively even as the groundwater situation has been turning rapidly from bad to worse. The scale of the groundwater threat is long recognized; but viable strategies for dealing with it are not forthcoming; indeed, governments are still busy promoting more groundwater development, as if they were in stage 1. This is true for South Asia, but it is also true for North China.[7]

In principle, the groundwater threat can be met, provided national administrations can build a tight resource management regime well in time that focuses on both demand- and supply-side interventions. The catch is that nowhere in the world – barring in very rich countries – do we find such an ideal regime actually in operation. Worldwide, then, there is some action by way of a response to groundwater degradation, but it is too little, too late, too experimental, too curative, and too supply-side-oriented. There is precious little done to reduce demand for groundwater or on approaches to economizing on its use. The only examples we can find that combine demand- and supply-side interventions are in western USA, which has suffered amongst the most extensive groundwater depletion problems anywhere in the world, and before anyone else did.[8] The examples of western USA provide important pointers to the rest of the world about where to direct ameliorative action (see Peck, Chapter 14, this volume). A major problem in transferring these lessons wholesale to the developing country context, however, is the numbers involved: in a typical groundwater district in the USA, the total number of farmers is probably less than 1000; in an area of comparable size, Asia would have over 100,000 farmers (see Table 2.5). The average stakes per farmer too would 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, obtaining a permit is mandatory for all groundwater users, but small users extracting water for domestic or livestock needs, or for irrigating small plots of 2 ha or less, are exempt (see Turral, Chapter 15, this volume). If this exemption were to be applied in South Asia or the North China Plain, more than 95% of groundwater irrigators would be exempted (Shah *et al*., 2006).

Legal/regulatory initiatives tried worldwide

The differing rules for obtaining a permit for groundwater irrigation is perhaps why Asian and other developing country governments tend to rely more heavily on enacting laws to regulate groundwater use and abuse. Although South Asia is yet to embark on this path, there is little evidence to suggest that water laws deliver the desired regulation, either in Asia or elsewhere in the developing world. China is way ahead of South Asian countries in legislative and regulatory measures to rein in groundwater withdrawals. Its new water law requires that all the pumpers get a permit; but the law is yet to be enforced. Only in deep tube well areas of the North China Plain are tube well owners obliged to get individual permits; elsewhere, the village as a whole holds a permit to use groundwater, which has little operational meaning. China's water administration is able to extract close to an economic price from canal irrigators; but groundwater is still free (Shah *et al.*, 2004a). South Africa's new water law and water policy enshrine the principles of 'user pays; polluter pays'; they work well in the commercial farm economy dominated by large-scale white farms but would fail to impact areas of 'black irrigation' in the former homelands. India has been toying around with a draft model groundwater bill for more than 30 years; but is not able to make it into a law due to doubts about enforcing such a law on more than 19 million irrigation pumpers scattered across a vast countryside. The establishment of Aquifer Management Councils called COTAS (*Consejos Técnicos de Aguas*) in Mexico as part of its water reforms and under the new Mexican water law is a notable development of interest to South Asia's groundwater policymakers. However, IWMI researchers in Guanajuato, Mexico are skeptical and hopeful at the same time:

> [S]everal factors bode ill for their (COTAS) future effectiveness in arresting groundwater depletion. Most importantly, their main role will be advisory in nature and they will 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-governing, collective action and to find innovative solutions to the vexing problem of groundwater depletion. (Wester *et al.*, 1999)

A recent assessment of what COTAS have achieved is even gloomier. Mexican attempts to nationalize water, and create groundwater rights by issuing concessions to all users who are working in organized industry and with municipal users – sectors where these reforms are the least needed for effective regulation; however, in the farming sector, groundwater concessions have come unstuck. A major problem is the high transaction costs of enforcing the terms of the concession on 70,000 tube well owners and a similar number of farmers who impound rainwater in private *bordos* (ponds) in the highlands of Northern Mexico (Shah *et al.*, 2004b). South Asia is often advised to draw a leaf out of the book of Mexican water reform; but it is easy to imagine how difficult it would be to enforce such a regime on 19 million tube well owners when Mexico has been finding it difficult to enforce it on 70,000 groundwater irrigators.

Equitable control

Institutional solutions to sustainable groundwater management that have a chance to work may pose complex issues of equity and political economy. Some of these became evident in the tiny and experimental World Bank–supported Taiz project in the Habir aquifer of Yemen with the objective to develop a partnership between rural and urban groundwater users to transfer water from the countryside to a town on equitable terms and ensure the sustainability of the resource. The project – which affected a small group of 7000 rural residents on the Habir aquifer – failed to either transfer water or ensure its sustainability, but suggested important lessons about why it failed. Taking an egalitarian stance, the project tried capacity building of all the 7000 residents to assume rights over the aquifer and manage the transfer of water to the city; however, the real stakeholders were 22 irrigation pumpers – who used over 90% of the aquifer – and not the 7000 residents. The practicalities of achieving the project aims required that the de facto rights of these 22 users were recognized, and incentives created for *them* to sustainably manage the resource. The pumpers, however, opposed, got frustrated and sabotaged all institutional efforts that infringed their de facto rights and failed to provide *them* incentives for sustainable management – which meant that sustainability could be possible only by reinforcing existing inequalities. The report on a World Bank Consultation that analysed the lessons of the Taiz project concluded: 'In our judgment, "the egalitarian option" is not viable and ultimately counter productive since it is unlikely to work' (Briscoe, 1999, p. 12).

Indirect levers

There are potentially powerful *indirect* demand-management strategies that are not even part of the academic discussion on groundwater management in the developing world. For example, it has been suggested that India Punjab's groundwater depletion problems could be easier to resolve if its export of 'virtual' groundwater in the form of rice could be reduced or stopped. IWMI researchers have suggested that in the North Indian plains, using earthen canals for recharging with flood water of monsoon rains can help counter groundwater depletion (IWMI–Tata Water Policy Briefing 1). Water-saving irrigation research – such as Alternate Wet and Dry Irrigation (AWADI) for rice in China or the System of Rice Intensification, which has found enthusiastic following in scores of countries including India and Sri Lanka (Satyanarayana, 2005; Sinha and Talati, 2005) – can help reduce groundwater use; but it needs to be examined if these technologies would work as well in dry areas. In many developing countries, pricing and supply of electricity to tube well owners can offer powerful levers for agricultural demand management for groundwater. Since levying a price on groundwater itself may entail high transaction costs of collection, energy price can serve as a useful 'surrogate' (Scott and Shah 2004; Shah *et al.*, 2004c).

Energy-irrigation nexus

Another key area in the groundwater economy of South Asia, especially India, is the perverse energy subsidies for tube well irrigation. In the populous South Asian region, there seem no practical means for direct management of groundwater; laws are unlikely to check the chaotic race to extract groundwater because of the logistical problems of regulating a large number of small, dispersed users; water pricing and/or property right reforms too will not work for the same reasons. However, electricity supply and pricing policy offer a powerful tool kit for *indirect* management of both groundwater and energy use. Since electricity subsidies have long been used by governments in this region to stimulate groundwater irrigation, the fortunes of groundwater and energy economies are closely tied. India is a classic example. Today, India's farmers use subsidized energy worth $4.5–5 billion/year to pump 150 km^3 of water mostly for irrigation; the country's groundwater economy has boomed by bleeding the energy economy. With the electricity industry close to bankruptcy, there are growing demands for eliminating power subsidies; but governments are unable to do so because of stiff opposition from the farmer lobby. Recent IWMI research (Shah *et al*., 2004c) has argued that sustaining a prosperous groundwater economy with a viable power sector is feasible, but it requires that the decision makers in the two sectors jointly explore superior options for energy–groundwater co-management. IWMI studies recognize that switching to volumetric electricity pricing may not be politically feasible at present. However, they advocate a flat tariff accompanied by better management of high quality but carefully rationed power supply to maintain at once the financial sustainability of energy use in agriculture and the environmental sustainability of groundwater irrigation. They argue that such a strategy can curtail wasteful use of groundwater in irrigation to the extent of 15–18 km^3/year.

Supply-side responses

Where the problem has begun to pinch hard, the Asian response to groundwater depletion has been supply-side rather than demand-side. The standard reasoning is that even after building 800,000 big and small dams around the world, the reservoirs can capture and store no more than one-fifth of the rainwater, the bulk of the remainder still running off to the seas. In India, which has built more than its share of the world's dams, 1150 km^3 of the rainwater precipitation still runs off to the seas annually in the form of 'rejected recharge' (INCID, 1999). If a fraction of this could be stored underground by reducing the velocity of the runoff and providing time for recharge, groundwater supplies could be enhanced significantly. But this presumes *active* aquifer management where planned drawing down of the water table in the premonsoon dry months is an important element of the strategy for enhancing the recharge from monsoon rainwater as well as from irrigation return flows. Such proactive 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 western Germany, 25% in Switzerland, 22% in the USA, 22% in Holland, 15% in Sweden and 12% in England (Y. Li, 2001).

Mega projects for interbasin transfer of water from surplus to deficit basins are increasingly talked about in groundwater irrigation areas of Asia. China is already executing a mega project for trans-basin diversions of approximately 25 km^3/year of water from the Yangtzi river in the water-surplus South to the water-scarce Yellow River basin in the North (Keller *et al*., 2000). India has for a long time talked about a garland canal to link Himalayan rivers with Cauvery and other South Indian rivers; these have so far remained at the ideas level but with the passing of every drought, these seemingly impractical ideas acquire new appeal and credibility. In 2002, the Supreme Court of India enjoined the central government to undertake such linking of rivers on a war footing partly to alleviate the pressure on groundwater in western and peninsular India. Gujarat, the western Indian state chronically dependent on groundwater overdraft for its agriculture, has already started using interbasin transfer of water from the controversial Narmada project to counter groundwater depletion in parts of Saurashtra and North Gujarat.

The economics of interbasin transfer are deeply influenced by the groundwater economy. In Gujarat, for example, it has been argued that the overall economics of the Narmada project become far more favourable when we include into the cost–benefit calculus the beneficial impact of Narmada waters in significantly countering groundwater depletion in North Gujarat where farmers are using subsidized electricity to pump groundwater from 250 to 300 m. The saving of electricity subsidy required to sustain groundwater-irrigated agriculture and rural livelihood systems in such regions can tilt the cost–benefit ratios in favour of surface irrigation projects.

Reviving and improving upon forgotten traditions

Some of the water-scarce regions of Asia have age-old traditions and structures for rainwater harvesting, which have fallen into disuse and are now attracting renewed attention (see Sakthivadivel, Chapter 10, and Mudrakartha, Chapter 12, this volume). India's Central Ground Water Board has been harnessing support for a National Groundwater Recharge Programme. Tarun Bharat Sangh and Pradan, two local non-governmental organizations (NGOs) in the Alwar district of western Rajasthan whose work IWMI has been studying, have helped local communities to rehabilitate centuries-old tanks (known locally as *johads* or *paals)* with dramatic impact on groundwater recharge and revival of dried-up springs and rivulets in a 6500 km^2 area (Agarwal, 2000). In southern India, where centuries-old tanks are on a decline, wells are widely thought of as enemies of tanks. Until the 1960s, when modern tube well 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. Recently, better-off farmers have been able to increasingly privatize tank water by sinking tube wells in their surrounding. As a result, their stakes in maintaining tanks declined; and so did the age-old traditions of tank management.

However, in the western region of India, hit hardest by groundwater depletion, well owners have become great champions of tanks because they keep their wells productive (Sakthivadivel *et al*., 2004). Catalysed first by spiritual Hindu organizations – such as the *Swadhyaya Pariwar* and *Swaminarayana Sampradaya* – and supported by numerous local NGOs, local communities have spontaneously created a massive water-harvesting and recharge movement based on the principle: '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'. As many as 300,000 wells – open and bore – have been modified by the people to divert rainwater to them; and thousands of ponds, check dams and other rainwater harvesting and recharge structures have been constructed on the basis of the self-help principle to keep the rainwater from gushing into the Arabian Sea (Shah, 2000). While systematic studies are still to begin of the impact of the movement and the popular science of rainwater harvesting and decentralized recharge that has emerged as a result of farmers' experiments, available indicative evidence suggests that for regions critically affected by groundwater depletion, only mass popular action on regional scale may be adequate to meet the challenge of depletion (Shah and Desai, 2002).

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. One indication of the seriousness assigned to the issue by Indian leadership is the message delivered by the prime minister to the citizens on 26 January 2004, India's 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.

From Resource Development to Management Mode

In the business-as-usual scenario, problems of groundwater overexploitation not just in South Asia but throughout the region will only become more acute, widespread, serious and visible. The front-line challenge is not just supply-side innovations but to put into operation a range of corrective mechanisms before the problem becomes either insolvable or not worth solving. This involves a transition from resource 'development' to resource 'management' mode (Moench, 1994, see also Moench, Chapter 9, this volume). Throughout Asia – where symptoms of overexploitation are all too clear – groundwater administration still operates in the 'development' mode, treating water availability as unlimited, and directing their energies on enhancing groundwater production. A major barrier that prevents transition from the groundwater *development* to *management* mode is lack of information. Many countries with severe groundwater depletion problems do not have any idea of how much groundwater occurs, and who withdraws how much groundwater and where. Indeed, even in European countries, where groundwater is important in all uses, there is no systematic monitoring of groundwater occurrence and draft (Hernandez-Mora *et al*., 1999). Moreover, compared to reservoirs and canal systems, the amount and quality of application of science and management to national groundwater sectors has been far less primarily because, unlike the former, groundwater is in the private, 'informal' sector, with public agencies playing only an indirect role.

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

1. Recognizing that even as the bulk of the public policy and investments is directed at large government-managed irrigation programmes, in reality, South Asia's agriculture has increasingly come to depend upon small-holder irrigation based largely on groundwater; policy effort as well as resource investments need to adjust to this reality if these are to achieve *integrated* water and land resources management in the true sense.
2. Implementing information systems 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.
3. Initiating some form of demand-side management by: (i) registering users through a permit or license system; (ii) creating appropriate laws and regulatory mechanisms; (iii) employing a system of pricing that aligns the incentives for groundwater use with the goal of sustainability; (iv) promoting conjunctive use of surface and groundwaters by reinventing main system management processes to fit a situation of intensive tube well irrigation in command areas; and (v) promoting 'precision' irrigation and water-saving crop production technologies and approaches.
4. Initiating supply-side management by: (i) promoting mass-based rainwater harvesting and groundwater recharge programmes and activities; (ii) maximizing surface water use for recharge; and (iii) improving incentives for water conservation and artificial recharge.
5. Undertaking groundwater management in the river basin context. Groundwater interventions often tend to be too 'local' in their approach. Past and forthcoming work in IWMI and elsewhere suggests that like surface water, groundwater resources too need to be planned and managed for maximum basin level efficiency. A rare example where a systematic effort seems to have been made to understand the hydrology and economics of an entire aquifer are the mountain aquifers underlying the West Bank and Israel. The actual equity effects of shared management by Israelis and Palestinians here are open to controversy; however, this offers an early example of issues that crop up in managing trans-boundary aquifers (Feitelson and Haddad, 1998). Equally instructive for the developing world will be the impact of the entry of large corporate players in the business of using aquifers as interyear water storage systems for trading of water.

As groundwater becomes scarce and costlier to use in relative terms, many ideas – such as trans-basin movement or surface water systems exclusively for recharge – that in the yesteryears were discarded as unfeasible or unattractive, will now offer new promise, provided of course that Asia learns intelligently from these ideas and adapts them appropriately to its unique situation.

Conclusion

South Asia has experienced a veritable boom in groundwater irrigation over the last 35 years. This boom is a manifestation of the struggle of the region's peasantry to survive in the midst of inexorable increase in population pressure on farmland. Because small pumps and boreholes have proved one of the most potent land-augmenting technologies, smallholders in India, Bangladesh, Nepal Terai and Pakistan have taken to bore well irrigation with great enthusiasm.

Our analysis suggests that this enthusiasm has proved to be well founded, and that farmland productivity through Green Revolution technology has experienced a quantum jump thanks to the spread of groundwater irrigation. Wells have also brought greater spatial, social and interpersonal equity in access to irrigation, especially when compared to large public canal irrigation systems that have created islands of agrarian prosperity. Indeed, it can be safely said that the groundwater boom has been amongst the best things that have happened for South Asia's rural poor in the past few decades, and the size and dispersion of the livelihood benefits of this boom can arguably outcompete some of the best-known poverty alleviation programmes in the region.

The key concern in South Asia is managing this boom for socio-economic as well as environmental sustainability. Evidence is mounting that this runaway economy is taking its toll on wetlands, lean-season river flows, groundwater levels as well as quality. Evidence is also mounting that, unless effectively regulated, further indiscriminate expansion of bore well irrigation – except in pockets like the eastern Gangetic basin – will undo all the good it is doing to South Asia's poor. The sense of urgency about building effective mechanisms for governing the groundwater economy is already being felt. The challenge for the region's decision makers is to evolve a strategy unique to its peculiarities rather than blindly adopting approaches tried in groundwater economies with a totally different architecture.

Even if South Asia experiments with direct regulation of groundwater abstraction – such as licensing of bore wells, withdrawal permits and water fees – it should not bank on these schemes. It should instead devise a tool kit of *indirect instruments* to regulate overall groundwater abstractions. This requires that water policymakers eschew hydrocentric vision and embrace a broader, strategic view of groundwater governance. It is also important to realize that for a long time to come, the most potent response to groundwater overdevelopment in South Asia would come from effective supply-side interventions. Therefore, South Asia should scale up its commitment of financial and scientific resources to groundwater recharge management to a level commensurate with the high and increasing dependence of the region on groundwater resource.

Notes

1 This is an official Government of India estimate. Independent researchers suggest that the proportion is likely much higher. An IWMI survey of 2629 farmers from 278 villages across India, Pakistan Punjab and Sind, Nepal Terai and Bangladesh showed that groundwater wells serve as sole or complementary sources in serving 75% of irrigated areas in the entire sample; this ratio was higher at 87% for the Indian sample (Shah *et al*., 2005).

2 For example, Henry Vaux, a senior agricultural economist from the University of California at Davis asserts: 'Persistent groundwater overdraft is self-terminating' (Vaux, personal communication, El Escorial, 2005).

3 This was when oil prices were less than half of their cost in October 2005.
4 It uses a district-wise data-set compiled by Bhalla and Singh (2001) covering 273 districts of India and provides data for the value of 35 agricultural crops at 1990 base year price (in rupees, which has been converted to dollars according to the 1990 rupee/dollar exchange rate) for four decades – 1960s to 1990s. These 35 crops cover more than 90% of the crop output and area cultivated in India. We have worked out productivity figures by dividing the value of these 35 crops (in dollars) by the net cropped area in the district. Bhalla and Singh (2001) span data across 273 districts (1960 base), and include all states except Himachal Pradesh and the North-eastern states.
5 Similar evidence is available from other parts of the world as well (see Hernandez-Mora *et al.*, 1999, for a comparative study in Andalucia, Northern Spain).
6 1$ = Pak Rs. 65 in September 2001.
7 A scholar of the Chinese groundwater degradation problem recently wrote: ‘For more than twenty years – since almost immediately after large-scale mechanized groundwater pumping began – Chinese scientists have observed, reported, and warned against the dangers of ground water declines. 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. Ground water investigations on 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).
8 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 for new institutions to be created, 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, besides these supply-side interventions, there were also measures to restrict the withdrawals through the creation of groundwater zones and the levy of groundwater tax that varied across zones according to the cost of alternative supplies. As a result, in the mid-1980s, the groundwater table stabilized at 30 feet above the historic lowest, and land subsidence became a matter of the past (Coe, 1989).

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