7 Groundwater Irrigation in India

Growth, Challenges, and Risks

Vasant P. Gandhi and Vaibhav Bhamoriya†

Introduction

Groundwater has rapidly emerged to occupy a dominant place in India's agriculture and food security in recent years. Over the past three decades it has become the main source of growth in irrigated areas, and now accounts for over 60 per cent of the irrigated area in the country. It is estimated that over 70 per cent of India's food grain production now comes from irrigated agriculture in which groundwater plays a dominant role. Since the growth in groundwater irrigation has not been largely government or policy driven and has happened mainly through highly decentralized private activity, the groundwater revolution has gone by and large unnoticed.

However, despite its huge significance and importance, groundwater irrigation is heading for a crisis and needs urgent attention and understanding in India. The number of irrigation blocks labelled as overexploited is increasing at an alarming rate of 5.5 per cent per year. The number of blocks in which officially the creation of wells must completely stop is scaling new heights every year. Yet, the sinking of new wells continues rapidly, at enormous private, public, and environmental costs. The way India will manage its groundwater resource will clearly have serious implications for the future growth and development of the water resources, agriculture, and food sectors in India, as well as the alleviation of poverty.

Size and Profile of India's Groundwater Resource and its Development

How much groundwater is available? The estimated total replenishable groundwater resource in India is 433.02 billion cubic metres (BCM) per year (see Table 7.1). The groundwater available for irrigation is estimated to be about 93 per cent of this or 403.85 BCM (after allowing about 7 per cent for domestic, industrial, and other uses). Out of this the utilizable groundwater resource for irrigation is 381.16 BCM, or 88 per cent. The annual net draft is estimated to be about 212.51 BCM so far. Thus, groundwater development is about 58 per cent of the potential in the aggregate, which may not appear so alarming. However, this number does not reveal the true picture of geographic variation, which is rather extreme.

What is the geographic distribution by river basin? Table 7.2, which gives the river basin-wise groundwater potential in the country shows that out of the total replenishable groundwater resource of 431.42 BCM, the Ganga basin alone accounts for nearly 40 per cent. Thus, the resource is highly concentrated and none of the other basins even cross 10 per cent. The basins with more than 5 per cent of the total replenishable potential are Godavari (9.42 per cent), Brahmaputra (6.15

† The authors gratefully acknowledge the contribution of N.V. Namboodiri.

TABLE 7.1 Dynamic Groundwater Resources of India, 2004 (in BCM per year)

1. Total replenishable groundwater resources	433.02
2. Provision for domestic, industrial, and other uses	29.17
3. Available groundwater resources for irrigation in net terms	403.85
4. (3) as per cent of (1)	93.26
5. Utilizable groundwater resources for irrigation in net terms	381.16
6. Gross draft estimated on prorate basis	230.62
7. Net draft	212.51
8. Balance groundwater resources for future use in net terms	162.29
9. Level of groundwater development	58 %

Source: Central Ground Water Board (2006).

TABLE 7.2 River Basin-wise Groundwater Potential of the Country

S. No.	*Name of basin*	*Total replenishable groundwater resources (BCM)*	*Percentage*
1	Ganga	170.99	39.63
2	Godavari	40.65	9.42
3	Brahmaputra	26.55	6.15
4	Indus	26.49	6.14
5	Krishna	26.41	6.12
6	North-east composite	18.84	4.37
7	Madras and South Tamil Nadu	18.22	4.22
8	Western Ghat	17.69	4.10
9	Mahanadi	16.46	3.82
10	Cauvery	12.3	2.85
11	Kutch & Saurashtra composite	11.23	2.60
12	Narmada	10.83	2.51
13	Meghna	8.52	1.97
14	Tapi	8.27	1.92
15	Cambay composite	7.19	1.67
16	Pennar	4.93	1.14
17	Brahmai with Baitarni	4.05	0.94
18	Subarnrekha	1.82	0.42
	Total Resources in BCM	431.42	100

Source: Ministry of Water Resources (2007).

per cent), Indus (6.14 per cent), and Krishna (6.12 per cent). This shows that the distribution of groundwater is highly skewed, and averages and aggregates may hide the real picture on the ground in various areas.

What is the state-wise profile of irrigation and groundwater potential? Table 7.3 shows that the estimated ultimate irrigation potential of the country is about 140 million hectare of irrigated area. Of this the potential for groundwater is estimated to be 64 million hectare, or 45.8 per cent. The proportion of groundwater in the irrigation potential varies substantially from state to state. It ranges from over 50 per cent in states, such as Uttar Pradesh, Madhya Pradesh, Jammu and Kashmir, Manipur, and Tamil Nadu, to around 33 per cent (one-third) in the case of Rajasthan, Kerala, Haryana, and Assam, and is negligible in many other states.

What is the level of development of the groundwater across different states? Table 7.4 gives the state-wise profile of the total replenishable groundwater resource, its availability for irrigation, the existing net draft, and therefore the percentage level of groundwater development. The states are arranged in descending order of the per cent of groundwater development.

Table 7.4 brings out the alarming picture of groundwater development in many states. The level of groundwater development is already as high as 141 per cent in Punjab, 111 per cent in Rajasthan, and 105 per cent in Haryana. This is followed by Tamil Nadu at 81 per cent, Gujarat at 70 per cent, and Uttar Pradesh/Uttarakhand at 65 per cent. There are large differences across the states. Further, these figures hide the highly skewed intra-state distribution, as is known in states, such as Gujarat and Rajasthan.

What is the prevalence of well irrigation across states in India? The prevalence of irrigation and well irrigation across states by village frequencies is shown in Table 7.5, which shows that over 63 per cent of the villages in India had tube wells by 2002. Given the growth of groundwater irrigation in India in the last decade this prevalence may have increased significantly by now. The states where the proportion of villages having tube well irrigation is above the national average are Punjab, Himachal Pradesh, Uttar Pradesh, Haryana and Bihar.

In states, such as Maharashtra, Gujarat, Rajasthan, and Madhya Pradesh, a large percentage of villages show the presence of other wells. However, the frequency of tube wells is also very high in Gujarat, Rajasthan, and Madhya Pradesh. These figures indicate the predominance of tube well irrigation across a large number of states in the country.

Growth of Groundwater Irrigation in India

What has been the pace of growth of irrigated area and its composition by source/method over the years? The growth in irrigated area and the rising contribution of groundwater can be seen from the data and analysis given in Table 7.6. The net irrigated area tripled from 21 million hectares in 1950–1 to 63 million hectares in 2008–9; the share of groundwater irrigation through wells rose substantially from 28 per cent to 61 per cent. The main contribution in this came from rapid growth in tube well irrigation, the share of which rose from zero in 1950–1 to over 41 per cent by 2008–9. This shows that groundwater irrigation, and within that tube well irrigation technology, has made a huge contribution to irrigation growth in India.

Overall, the green revolution technology has been a central driving force. Beginning in the mid-1960s, the green revolution was a major turning point for India's agriculture. The adoption of new high yielding variety seeds and the accompanying use of fertilizers provided great benefits, and the gains were the best with irrigation. Huge investments were undertaken for surface water irrigation projects to provide irrigation water over vast areas to larger numbers of farmers. Besides, many other significant changes also took place in the late 1960s and 1970s (Briscoe and Malik 2006). Electricity supply expanded in rural areas making pumping of groundwater easy and economical. New modular well and pumping technologies became widely available. In the surface irrigated and flood-prone areas, water-logging and/or salinity were problems, and it was realized that encouragement of groundwater pumping provided a good mechanism for lowering the groundwater table and reducing the severity of the problems. Farmers realized that groundwater was abundant in many areas, especially in the large alluvial basins. The reach of institutional credit expanded making credit more widely available. Farmers realized that they could develop and apply water 'just in time' from groundwater sources, something which was not possible in the institutionally-complex and poorly managed canal systems.

TABLE 7.3 State-wise Ultimate Groundwater Irrigation Potential, 2001–2

	Total irrigation potential ('000 ha)	*Groundwater potential ('000 ha)*	*Share of groundwater in total ultimate irrigation potential*
Manipur	604	369	61.1
Uttar Pradesh*	30,499	16,799	55.1
Madhya Pradesh*	17,932	9,732	54.3
Jammu & Kashmir	1,358	708	52.1
Tamil Nadu	5,532	2,832	51.2
Punjab	5,967	2,917	48.9
West Bengal	6,918	3,318	48.0
Orissa	8,803	4,203	47.7
India	139,893	64,050	45.8
Gujarat	6,103	2,756	45.2
Karnataka	5,974	2,574	43.1
Maharashtra	8,952	3,652	40.8
Meghalaya	168	63	37.5
Bihar*	13,347	4,947	37.1
Andhra Pradesh	11,260	3,960	35.2
Rajasthan	5,128	1,778	34.7
Kerala	2,679	879	32.8
Haryana	4,512	1,462	32.4
Assam	2,870	900	31.4
Tripura	281	81	28.8
Goa	116	29	25.0
Himachal Pradesh	353	68	19.3
Arunachal Pradesh	168	18	10.7
UTs	144	5	3.5
Mizoram	70	0	0.0
Nagaland	85	0	0.0
Sikkim	70	0	0.0

Source: Ministry of Water Resources (2007); Ministry of Statistics and Programme Implementation (2010).
Note: * Figures include the Ultimate Irrigation Potential (UIP) for Jharkhand, Chhattisgarh, and Uttaranchal in the UIP of Bihar, Madhya Pradesh, and Uttar Pradesh respectively.

The result was a revolution, in which groundwater irrigation developed at a very rapid rate (Briscoe and Malik 2006), while tank irrigation declined and surface water irrigation grew much more slowly (see Figure 7.1).

Briscoe and Malik (2006) report that cheap and un-metered electricity, slow development of surface irrigation, and poor management of canal systems further encouraged groundwater development. Over

TABLE 7.4 State-wise Groundwater Resource and its Development in India

Sl. No.	States	Total replenishable groundwater resource BCM/yr	Available groundwater resources for irrigation BCM/yr	Net draft BCM/yr	Level of groundwater development [%]
1	Punjab	23.78	21.44	30.34	141.51
2	Rajasthan	11.56	10.38	11.60	111.75
3	Haryana	9.31	8.63	9.10	105.45
4	Tamil Nadu	23.07	20.76	16.77	80.79
5	Gujarat	15.81	15.02	10.49	69.84
7	Uttar Pradesh	76.35	70.18	45.36	64.63
8	Uttaranchal	2.27	2.10	1.34	63.80
9	Karnataka	15.93	15.30	9.75	63.72
10	All-India	433.02	399.25	212.51	53.22
11	Maharashtra	32.96	31.21	14.24	45.62
12	Madhya Pradesh	37.19	35.33	16.08	45.51
13	Andhra Pradesh	36.50	32.95	13.88	42.12
14	West Bengal	30.36	27.46	10.84	39.47
15	Bihar	29.19	27.42	9.39	34.25
16	Kerala	6.84	6.23	1.82	29.21
17	Himachal Pradesh	0.43	0.39	0.09	23.08
18	Assam	27.23	24.89	4.85	19.49
20	Chhattisgarh	14.93	13.68	2.31	16.89
21	Goa	0.28	0.27	0.04	14.81
22	Orissa	23.09	21.01	3.01	14.33
23	Jharkhand	5.58	5.25	0.70	13.33
25	Jammu & Kashmir	2.70	2.43	0.10	4.12
26	Tripura	2.19	1.97	0.08	4.06
27	Arunachal Pradesh	2.56	2.30	Neg.	Neg.
28	Meghalaya	1.15	1.04	Neg.	Neg.
29	Manipur	0.38	0.34	Neg.	Neg.
30	Nagaland	0.36	0.32	Neg.	Neg.

Source: Central Ground Water Board (2006); Ministry of Water Resources (2007).
Note: Estimates for 2004; BCM = Billion Cubic Metres.

the last two decades, 84 per cent of the total addition to net irrigated area has come from groundwater, and only 16 per cent from canals. Thus, at present the net area irrigated by private tube wells is about double the area irrigated by canals.

Historically, in the early phase of groundwater development in the 1950s, groundwater extraction was dominated by traditional dug wells with depths generally not exceeding 30 feet. Labour or animal devices, such as Persian wheels were often used to lift the water,

TABLE 7.5 State-wise Frequency of Villages having Irrigation Facility per 1,000 Villages, and their Distribution by Type of Such Facility in India (July–December 2002)

Sr. No.	*States/UTs*	*Number of villages having irrigation facility per 1,000 villages*	*Per cent of villages having tube well irrigation*	*Per cent of villages having other well irrigation*
1	Punjab	976	92.2	2.4
2	Himachal Pradesh	382	83.5	0.0
3	Uttar Pradesh	987	82.1	2.2
4	Haryana	979	81.4	1.3
5	Bihar	895	68.6	0.4
6	India	762	63.1	21.3
7	Karnataka	829	59.3	11.7
8	Rajasthan	893	54.3	34.6
9	Gujarat	891	50.6	47.3
10	Chhattisgarh	652	44.6	11.3
11	West Bengal	845	43.9	7.3
12	Andhra Pradesh	796	43.8	7.8
13	Madhya Pradesh	925	40.6	39.6
14	Tripura	685	38.5	2.2
15	Uttaranchal	391	36.8	0.0
16	Orissa	281	31.3	0.0
17	Puducherry	1,000	24.4	0.0
18	Mizoram	188	22.3	68.1
19	Dadra & Nagar Haveli	573	22.3	22.3
20	Daman & Diu	749	19.2	36.0
21	Tamil Nadu	879	13.9	39.6
22	Maharashtra	804	9.5	72.1
23	Kerala	840	7.0	28.8
24	Arunachal Pradesh	355	6.2	0.0
25	Jammu & Kashmir	708	4.4	0.0
26	Sikkim	618	0.2	8.4

Source: Ministry of Water Resources (2007).

constituting over 60 per cent of the irrigation devices. Sometimes, there was conjunctive use and hydrological nexus between well irrigation and tank irrigation (Jeet 2005). With this and the crop choice, the balance between demand and supply of water could be maintained except during years of very low rainfall, and therefore, water use was generally sustainable.

The second phase starting in the 1970s saw considerable growth of dug-cum-bore wells (Jeet 2005; Singh 2003). The depth of the wells increased to about 50 to 100 feet and the use of centrifugal pumps became common. More water could be lifted leading to increase in irrigated area and growing crops which required more water. With the easy availability of institutional

Table 7.6 Sources of Irrigation in India, 1950–1 to 2008–9 ('000 hectares)

Year	*Canal*	*Tanks*	*Tube wells*	*Other wells*	*Total wells*	*Other sources*	*Total net irrigated area*
1950–1	8,295	3,613	0	5,978	5,978	2,967	20,853
1960–1	10,370	4,561	135	7,155	7,290	2,440	24,661
1970–1	12,838	4,112	4,461	7,426	11,887	2,266	31,103
1980–1	15,292	3,182	9,531	8,164	17,695	2,551	38,720
1990–1	17,453	2,944	14,257	10,437	24,694	2,932	48,023
1995–6	17,120	3,118	17,894	11,803	29,697	3,467	53,402
2000–1	15,710	2,518	22,324	11,451	33,775	2,831	54,833
2005–6	16,644	2,088	23,849	12,235	36,084	5,974	60,790
2006–7	16,954	2,083	24,764	12,897	37,661	6,003	62,702
2007–8	16,690	1,968	26,328	12,033	38,361	6,080	63,099
2008–9	16,597	1,979	26,004	12,563	38,567	6,053	63,196
Percentage Share of Various Sources							
1950–1	39.78	17.33	0.00	28.67	28.67	14.23	100
1960–1	42.05	18.49	0.55	29.01	29.56	9.89	100
1970–1	41.28	13.22	14.34	23.88	38.22	7.29	100
1980–1	39.49	8.22	24.62	21.08	45.70	6.59	100
1990–1	36.34	6.13	29.69	21.73	51.42	6.11	100
1995–6	32.06	5.84	33.51	22.10	55.61	6.49	100
2000–1	28.65	4.59	40.71	20.88	61.60	5.16	100
2005–6	27.38	3.43	39.23	20.13	59.36	9.83	100
2006–7	27.04	3.32	39.49	20.57	60.06	11.39	100
2007–8	26.45	3.12	41.72	19.07	60.79	9.63	100
2008–9	26.26	3.13	41.15	19.88	61.03	9.58	100

Source: Gandhi and Namboodiri (2002); Ministry of Agriculture (2010).

credit for the construction of wells in the mid-1970s, the number of wells had increased substantially by late 1970. On the other hand, most of the tanks became unusable for irrigation due to poor maintenance and this resulted in even greater dependence on groundwater.

During the third phase beginning from the mid-1980s, the extraction technology started changing towards submersible pumps and the depth of wells increased to beyond 400 feet in many areas. Water extraction increased rapidly under the influence of subsidies on electricity, lack of metering, credit availability, and the commercialization of agriculture (Singh 2003). This led to rapid decline in the water table, decline in the quality of water, increased frequency of well failure, and rapidly rising costs of well investments and operations. This expansion of groundwater use resulted in a speedy decline in the groundwater table in several parts of the country (Bhatia 1992; Dhawan 1995; Moench 1992; and Dubash 2002).

The number of shallow wells doubled roughly every 3.7 years between 1951 and 1991 (Moench 2003), the total crossing 18.5 million wells nationwide and accounting for over 50 per cent of the irrigated area. By 2008–9, groundwater now provided for over 60

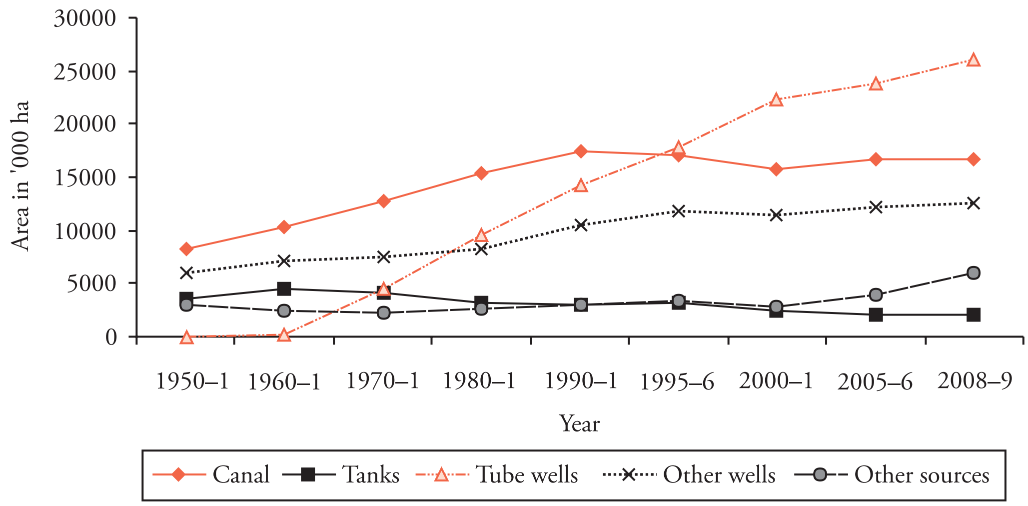

FIGURE 7.1 Sources of Irrigation in India

Source: Ministry of Agriculture (2010).

per cent of the irrigated area, and about 80 per cent of the domestic water supply year. The rapid expansion has resulted in steep declines in the groundwater table, low productivity of wells, intrusion of sea water in many areas, and deterioration in the groundwater quality. In arid regions, such as Rajasthan and Gujarat, ingress of naturally occurring brackish groundwater has become a matter of great concern. According to IWMI, the withdrawal rate in India is twice the recharge rate (Moench 2003). Thus, even though groundwater is a powerful tool for agriculture and poverty reduction, developing and managing this resource in a sustainable way is a tremendous challenge. Attempts to regulate groundwater through restrictions on credit and electric connections have had very little effect so far.

The Relative Efficacy, Efficiency, and Equity of Groundwater versus Surface Water

Efficacy and Efficiency

How does groundwater compare with surface water? Important work on this has been done by Moench (2003), and this section draws substantially on this research. Irrigation plays a major role in green revolution technologies and within this, groundwater irrigation is the best (Moench 2003). This is documented in a number of studies (see Meinzen-Dick 1996; Shah 1993). Farmers owning wells generally achieve the highest yields while those purchasing water from well owners achieve yields higher than those dependent on canal irrigation alone manage but not as high as the yields achieved by well owners (see Tables 7.7 and 7.8 based on these studies). Well irrigation is also associated with higher cropping intensity, higher cash input expenditure, and higher gross income per acre.

Other research indicates that yields in groundwater irrigated areas are higher by one-third to one-half as compared to those from areas irrigated by surface sources (Dhawan 1995). A wholly irrigated acre of land may become equivalent to 8 to 10 acres of dry land in production and income terms (Dhawan 1993). Some estimates suggest that as much as 70–80 per cent of India's agricultural output may be groundwater based (Dains and Pawar 1987). It is also found that well owners and those purchasing water tend to make more complementary investments in fertilizers, labour, and other inputs (Kahnert and Levine 1989). This increases the demand for these inputs and helps rural development (Moench 2003).

Shah (2003) indicates that numerous micro-level studies based on sample surveys show that pump-irrigated farms perform much better compared to those irrigated by any other source in terms of cropping intensity, input use, and yields (also see Dhawan 1985). By common observation, the difference between areas

TABLE 7.7 Average Yields of Major Crops by Water Source

Crop	*Canal only*	*Public tube well*	*Purchased from tube well*	*Own tube well*
Yield (kg/acre)				
Wheat	672	747	784	896
Rice	522	709	784	859
Cotton	261	299	373	485

Source: Moench (2003); Meinzen-Dick (1996); and Freeman et al. (1978).

TABLE 7.8 Input Use and Agriculture Productivity by Water Source

	Canal water only	*Tube well water buyers*	*Tube well owners*
Gross crop income (Rs/acre)	3,018	3,475	4,659
Canal Water use/acre (acre minutes)	26.3	26.2	25.2
Tube well water use (acre minutes)	0.0	14.2	31.4
Cash input expenditure (Rs/acre)	309	385	388
Labour use (man-days/acre)	73.8	76.2	75.5
Cropping intensity (per cent)	160	168	184
Per cent water consumptive crops	35	36	45

Source: Moench (2003); Meinzen-Dick (1996); and Renfro (1982).

irrigated by private tube wells and those irrigated by gravity flow canals is explained by superior quality in terms of reliability, timeliness, and the adequacy of irrigation that tube wells offer as compared to other sources (Chambers et al. 1987; Shah 1993).

Groundwater offers control and reliability of water in irrigation which proves very important. Experiments indicate that water control alone can bridge the gap between potential and actual yields by about 20 per cent (Herdt and Wickham 1978). In Spain, irrigation uses 80 per cent of all water and 20 per cent of water that comes from under the ground. But the 20 per cent produces more than 40 per cent of the cumulative economic value of Spanish crops (Barraque 1997). The contribution of groundwater is not just through higher yields. In arid regions, the stabilization effect of groundwater development may be substantial and have more than twice the benefit value of increase in water supply (Tsur 1990). In southern California, the stabilization value in agriculture is, in some cases, as much as 50 per cent of the total value of groundwater (Tsur 1993). The economic impact of droughts in California in the early 1990s was minimal largely because farmers were able to shift from unreliable surface supplies to groundwater (Gleick and Nash 1991).

In the Indian context, some insight on this can be gained through examining the impact of different droughts (Moench 2003). In the 1960s groundwater irrigation was relatively insignificant, particularly in eastern India. In 1965–6, when the monsoon rainfall was 20 per cent below normal, the food grain production declined by 19 per cent at the all-India level over the 1964–5 production level (Prasad and Sharma 1991). In 1987–8 when groundwater had been considerably developed, the rainfall dropped by 17.5 per cent below normal, and yet food grain production declined by only 2.14 per cent from the previous year. (Note: the droughts are not strictly comparable.) This appears to indicate the contribution of groundwater in improving the reliability of production.

Another way is comparing the standard deviation in the growth rates of irrigated and unirrigated agriculture for the period after the advent of new technology in the late 1960s. An analysis carried out for 11 major states for the period 1971–84, reveals that the degree of instability in irrigated agriculture was less than half of that in unirrigated agriculture (Rao et al. 1988) (see Table 7.9). The stability impact of irrigation was found to be much greater in low rainfall states, especially those served by assured sources of irrigation including tube wells (Haryana and Punjab), than in high rainfall areas, indicating an impact of groundwater irrigation. Bihar and Madhya Pradesh were the only states that exhibited higher fluctuation in irrigated agriculture as compared to unirrigated agriculture.

Equity

What is the nature and pattern in ownership and equity in groundwater irrigation? The Third Minor Irrigation Census conducted in 33 states and union territories during 2000–1 enumerated 18.5 million groundwater units. These comprised of 9.62 million dug wells, 8.35 million shallow tube wells, and 5.30 million deep tube wells. The distribution of well irrigation units by their ownership (Table 7.10) shows that 81 per cent of dug wells were owned by individual farmers, 16.8 per cent by groups of farmers, and very few by others. In shallow tube wells, 94.6 per cent were owned by individuals, 4 per cent by groups of farmers, and very few by others. In deep tube wells too, 61.8 per cent were owned by individuals, 27.6 per cent by groups of farmers, and about 10 per cent by the government/cooperatives/panchayats. On the other hand, the ownership of surface irrigation schemes was dominated by the government. Thus, the ownership of tube wells and dug wells for irrigation was largely with private individual farmers. Only in the case of deep tube wells, groups of farmers and the government showed some ownership, but individual farmers still dominated.

What is the ownership pattern by landholding size? Results from the same survey given in Table 7.11 indicate that over 67 per cent of the dug wells and shallow tube wells were owned by small and marginal farmers—those having operational holdings below 2 hectares. In the case of deep tube wells, about 60 per cent were owned by medium and large farmers. In the

Table 7.9 The Impact of Irrigation on Variability in Agricultural Output

State	*Irrigated agricultural output (1)*	*Unirrigated agricultural output (2)*	*Unirrigated to irrigated ratio (3=2/1)*
Standard Deviation in Annual Growth Rates, 1971–84			
Andhra Pradesh	13.6	18.8	1.38
Bihar	22.0	17.9	0.81
Gujarat	23.8	86.3	3.63
Haryana	9.3	54.8	5.89
Karnataka	16.7	31.4	1.88
Madhya Pradesh	24.5	23.0	0.94
Maharashtra	17.9	43.8	2.45
Punjab	4.9	19.3	3.94
Rajasthan	11.3	46.9	4.15
Tamil Nadu	19.2	41.6	2.17
Uttar Pradesh	12.0	40.0	3.33
Average	7.3	19.0	2.60

Source: Moench (2003), adapted from Rao et al. (1988).

TABLE 7.10 Distribution of Wells According to their Ownership, 2000–1

	Dug wells	*Shallow tube wells*	*Deep tube wells*	*Total*	*Surface flow*
Distribution According to Ownership (Number: 1,000)					
Government	172.0	47.8	50.3	270.2	264.8
Coop. societies	9.7	7.2	1.9	18.8	2.5
Panchayat	14.4	18.9	3.5	36.8	45.7
Groups of farmers	1,611.4	334.8	146.5	2,092.8	98.2
Individual farmers	7,784.5	7,901.7	0.0	15,686.2	217.0
Others	25.2	45.4	328.0	398.5	13.9
Total	9,617.4	8,355.7	530.2	18,503.2	642.0
Distribution According to Ownership (Percentage)					
Government	1.79	0.57	9.49	1.46	41.24
Coop. societies	0.10	0.09	0.36	0.10	0.38
Panchayat	0.15	0.23	0.66	0.20	7.11
Group of farmers	16.76	4.01	27.64	11.31	15.29
Individual farmers	80.94	94.57	0.00	84.78	33.80
Others	0.26	0.54	61.86	2.15	2.17
Total	100.00	100.00	100.00	100.00	100.00

Source: Ministry of Water Resources (2002a).

case of surface water, small and marginal farmers had a 72 per cent share. Thus, groundwater irrigation was less equitable than surface irrigation by landholding size, and deep tube wells were even less equitable. However, over two-third of dug wells and shallow tube wells were owned by small and marginal farmers.

Small and marginal farmers operated 36 per cent of the land whereas medium and large farmers operated 64 per cent of the land (see Table 7.11). Of all the wells, 66 per cent were owned by small and marginal farmers, and 34 per cent by medium and large farmers. This indicates that compared to land ownership, the distribution of ownership of wells was more equitable and was skewed in favour of small and marginal farmers. However, surface irrigation was more favourably distributed, with 72 per cent access with small and marginal farmers.

The distribution of crop season-wise irrigation by groundwater indicates that more area is irrigated by groundwater in the rabi season—about 50 per cent. About 35–38 per cent is irrigated in the kharif season, and about 8–10 per cent in perennial crops (Table 7.12). Thus, the rabi season, when rainfall is low, takes a major share of groundwater, yet the share of the kharif season, when the rainfall is high, is also substantial.

Moench (2003) states that the equity impacts of groundwater development for irrigation are not positive in every aspect. Modern tube well drilling and technology tend to be capital intensive. As a result, large farmers have an advantage. Early exploiters of groundwater have typically been large farmers who produce surpluses for the market. The World Bank (1999b) indicates that tying water rights to land rights has implications for access to groundwater and has *de facto* led to rights at the field level where due to the characteristics of groundwater as a common property resource, larger farmers with higher pumping capacity and deeper tube wells have a disproportionate claim over the resource than others.

Table 7.11 Distribution of Wells According to Farm Holding Size, 2000–1

Operational holding size	*Dug wells*	*Shallow tube wells*	*Deep tube wells*	*Total*	*Surface flow*	*Number of operational holdings (1995 in '000)*	*Area operated (1995 in '000)*
Distribution According to Farm Holding Size (Number: 1,000)							
Marginal (0–1 ha)	3,222.5	2,731.5	24.7	5,978.7	111.7	71,179	28,121
Small (1–2 ha)	2,924.9	2,890.5	35.7	5,851.1	114.2	21,643	30,722
Medium (2–10 ha)	3,007.9	2,273.6	68.5	5,350.0	65.5	21,353	80,351
Large (>10 ha)	240.7	340.9	17.6	599.2	23.8	1,403	24,163
Total	9,396.0	8,236.5	146.5	17,779.0	315.2	115,580	163,357
Distribution According to Farm Holding Size (Percentage)							
Marginal (0–1 ha)	34.30	33.16	16.85	33.63	35.45	61.59	17.21
Small (1–2 ha)	31.13	35.09	24.38	32.91	36.22	18.73	18.81
Medium (2–10 ha)	32.01	27.60	46.75	30.09	20.77	18.47	49.19
Large (>10 ha)	2.56	4.14	12.02	3.37	7.56	1.21	14.79
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Source: Ministry of Water Resources (2002a).

Table 7.12 Crop Season-wise Area Irrigated by Groundwater, 2000–1

	Dug wells	*Shallow tube wells*	*Deep tube wells*	*Total*
Crop Season-wise Area Irrigated by Groundwater (1,000 ha)				
Kharif	4,745.0	10,676.6	1,415.2	16,836.7
Rabi	6,988.1	13,284.7	2,000.0	22,272.7
Perennial	1,098.3	2,259.0	408.5	3,765.7
Others	391.9	1,452.7	262.4	2,107.0
Total	13,223.2	27,673.0	4,086.0	44,982.2
(Percentage)				
Kharif	35.88	38.58	34.63	37.43
Rabi	52.85	48.01	48.95	49.51
Perennial	8.31	8.16	10.00	8.37
Others	2.96	5.25	6.42	4.68
Total	100.00	100.00	100.00	100.00

Source: Ministry of Water Resources (2002a).

Singh (2003) indicates that this can be partly solved by water markets, which can mitigate the inequalities in access to groundwater. Farmers who do not have their own wells can have access to groundwater irrigation through water markets.

Groundwater can also be a key resource for poverty alleviation and economic development. Evidence indicate that improved water supply can generate many positive externalities in the overall household micro-economy. In areas dependent on irrigated agriculture, the reliability of groundwater and the resulting higher crop yield generally achieved, often enables farmers with small holdings to considerably increase their incomes (Moench 2003). The positive impact of well irrigation goes beyond those who own them as it also increases and stabilizes the demand for associated inputs, including labour. The expansion of well irrigation, therefore, can have a ripple effect in the rural areas including creating more employment.

In this context of inequality, CSE 1991 indicates that there are compelling reasons for stimulating rapid development of groundwater resources in eastern India. Eastern India has a bulk of India's poverty. It is largely rural, predominantly agricultural, and has a high population density. It has been argued that the green revolution in Punjab, Haryana, and western Uttar Pradesh was fueled more by the private tube well revolution, rather than only surface water, and why it has not progressed eastward to eastern India is explained by the slow pace of groundwater development in the east (Dhawan 1982). Besides, increased density of wells can increase the welfare of the people in the eastern region through the powerful positive externality that they produce by working against water-logging and flood-proneness. The CSE (1991) states:

> …that active development of groundwater reservoirs by extensive irrigation pumping during dry season can provide substantial capacity to store flood as well as the drainage waters during the wet season. Preliminary calculations made in USA indicate that full development of conjunctive use in the Ganga basin can lead to as much as 50 per cent reduction in the monsoon flows of rivers. Thus, groundwater utilization can not only contribute to full realization of the agricultural potential of the region but would also be effective in reducing and preventing water logging conditions which have come to be an imminent threat in considerable tracts of North Bihar [as indeed much of Eastern India]. The measure could considerably alleviate the flood problem of the region through provision of underground storage of monsoon flows. However, the desired development of groundwater in this area has been inhibited by the preponderance of marginal farmers who cannot afford the investment required in installation of tube wells….

The Role of Land Tenure, Water Rights, and Groundwater Markets in Influencing Equity and Efficiency

As per the law, groundwater is under private regime in India and the rights to groundwater belong to the owner of the land (Jeet 2005). The right to groundwater is transferred to anyone to whom the land is transferred. There is no limitation on how much groundwater a particular landowner can draw. Therefore, a landowner can legally abstract any amount of water unless the geo-hydrology or technology limits it. The consequence of such a legal framework is that only the landowners can own groundwater in India. The landless households or tribes who may have community rights over land have no private rights. The legal framework also implies that rich landlords can be water lords and indulge openly in extraction and selling of as much water as they wish (Singh 1991). The lack of well-defined property rights, the invisibility, and the complex flow characteristics of groundwater makes it very difficult to monitor its use (Singh 1995).

For wider access and control it is necessary to separate water rights from land rights, but no such provisions have been made so far in the national groundwater law (Jeet 2005). In Gujarat, the government tried to regulate water extraction and marketing by restricting the depth of tube wells and by introducing licensing procedures, but there has been little success. Since the groundwater situation in different parts of the country varies with factors, such as geology, hydrology, ecology, soil, climate, pattern of usage, and water quality, the nature of regulations for groundwater utilization may need to vary from area to area.

Water markets and trading can partly mitigate the inequalities in access to groundwater resources due to lack of ownership of land (Jeet 2005). They could work on the principle of profitability, and overexploitation could be checked through this. Though water markets exist, they are by and large limited to localized water trading between adjacent farmers. Water trading remains informal in the sense that there are often no formal methods or agreements. This hinders the reallocation of water for more productive use. In recent years it has become apparent that informal water markets have become widespread. One of the more complex and better operated of these informal markets is in Gujarat (The World Bank 1999b). Expanding the role of markets into a formal mechanism for water allocation necessitates a reform of the water rights framework, and the development of effective management institutions. The introduction of more formal water markets, where feasible, could further provide an opportunity for efficient reallocation using market mechanisms (The World Bank 1999a).

Who participates in the water market is an important indicator of the nature of water markets. Past studies show that the well owners with less holdings have a higher extent of participation than those who own larger holdings (Shah and Raju 1988). But a study done in Rajasthan (Singh 2003) does not support this hypothesis (see Table 7.13). This study shows that among the sellers only one-third belonged to the small and semi-medium size categories and two-third belonged to the medium and large farm size categories. On the other hand, a majority of the buyers belonged to the small and semi-medium size groups.

The same study finds that the main reasons given by self-users for non-participation in water markets were: lack of surplus water due to low discharge, followed by no buyers available, and water quality (see Table 7.14). On the other hand, the reasons for participation in the water market given by sellers were: having surplus water, earning profits, and power policy (particularly flat pricing). The major reasons given for participation in the water markets by the buyers were: owning land but no well, and limited and unreliable water supply.

Apart from the water markets, an important grassroots initiative on improving groundwater availability has been the check dam movement in the Saurashtra region of Gujarat. This involves the formation of

Table 7.13 Farm Size-wise Distribution of Households Participating in Water Markets (*per cent*)

Category	*Size of farms*					*Sample Size (No.)*
	Marginal	*Small*	*Semi-medium*	*Medium*	*Large*	
Kukanwali						
Self-users	0	0	15	77	8	13
Seller	0	11	21	42	26	19
Buyers	25	13	50	12	0	8
Overall	5	8	25	42	15	40
Srichandpura						
Self-users	17	50	33	0	0	6
Seller	33	33	34	0	0	6
Buyers	70	15	15	0	0	13
Overall	48	28	24	0	0	25
Overall						
Self-users	5	16	21	53	5	19
Seller	8	16	24	32	20	25
Buyers	52	14	29	5	0	21
Overall	22	15	25	29	9	65

Source: Singh (2003).

Table 7.14 Reasons for Participation or Non-participation in Water Markets (*per cent*)

Particulars	*Kukanwali*	*Srichandpura*	*All*
Self-users' reasons for not participating			
• No surplus water	46	83	58
• No buyers	38	17	32
• Water quality	16	0	10
Sellers' reasons for participating			
• Surplus water	74	83	76
• Profit earning	26	50	32
• Power policy	26	17	24
Buyer's reasons for participating			
• Owned land but no well	88	46	66
• Limited and fluctuating water supply	12	54	34

Source: Singh (2003).

village level local institutions in hundreds of villages to undertake the planning, financing, and construction of a system of check dams in and around the villages to collect and hold rainwater so as to recharge the underground aquifers and thereby recharge the dug wells. The movement appears to have had a huge impact on water availability and agricultural incomes in the area. The results of a study of these institutions by Gandhi and Sharma (2009), given in Table 7.15, indicates a large positive impact on water availability, irrigated area, participation-empowerment, village development, and on the environment.

Overextraction, Costs, and Externality Implications

Extraction of groundwater in excess of its replenishment is a serious problem and leads to significant declines in the groundwater table. Information on the broad official assessment of this is analysed in Table 7.16, which shows the distribution of different talukas/blocks in India into overexploited/dark/critical with respect to the status of groundwater. The situation may not look serious at the national level since the number of such blocks is below 20 per cent overall, and is lower in many states. However, the condition seems to be very precarious in states, such as Punjab, Haryana, and Rajasthan. In these locations the incidence of overexploitation is very high and the situation is becoming critical.

The assessment in Table 7.16 indicates that over 80 per cent of the blocks/assessment units were overexploited, dark, or critical in Rajasthan, which was closely followed by Punjab at 78.8 per cent, and Delhi at 77.8 per cent. In Haryana, Tamil Nadu, and Karnataka too the percentages were very high at 58.4, 45.5, and 38.9 respectively. Andhra Pradesh and Gujarat were also above the national average of 18.5 per cent.

Groundwater extraction has increased dramatically in India over the six decades since independence. Official statistics and projections indicate rapid growth in the area irrigated from groundwater, the number of wells, and the number of energized pump sets (The World Bank 1998). Data from the groundwater component of the World Bank–Government of India water sector strategy review (The World Bank 1998) clearly show the rapid rates of growth.

What factors contribute to this situation of overexploitation? In the interest of food security and inclusive growth, the government's policies have made subsidies and credit extensively available to farmers (Singh 2003). These have influenced power pricing and technology use which have strong linkages with groundwater development and use. These policies have

Table 7.15 Impact of Rainwater Harvesting and Groundwater Recharge by Check Dam Groups of Saurashtra Region in Gujarat—Members' Response

Per cent

Questions on the impact on: scarcity and efficiency equity empowerment development and environment	*Highly positive*	*Positive*	*No impact*	*Negative*	*Highly negative*
Timely water availability	44	56	0	0	0
Adequate water availability	56	44	0	0	0
Increase in irrigated area	45	55	0	0	0
Equitable distribution of water	0	0	100	0	0
Empowerment of farmers to manage irrigation systems	42	58	0	0	0
Beginning of a sense of ownership by farmers	61	39	0	0	0
Active involvement of all classes	30	70	0	0	0
Village as a whole	91	9	0	0	0
Environment and natural resources	83	17	0	0	0

Source: Gandhi and Sharma (2009).
Note: N=100.

fostered intensive groundwater utilization and a sharp increase in groundwater use has been recorded, leading to overexploitation. The expansion of groundwater use has resulted in a speedy decline in the groundwater table in several parts of the country (Bhatia 1992; Dhawan 1995; Moench 1992; and Dubash 2002). The evidence indicates that the fall in the water table is quite rapid in water scarce regions. In Rajasthan this decline is recorded at the rate of 1 to 5 metres per year in different conditions. If this trend continues then there will be irreparable loss, and socio-economic and environmental challenges will emerge. Immediate attention needs to be given to this.

The World Bank (1999b) indicates that there is no charge on groundwater itself and the present groundwater pricing structure provides minimal incentives for efficient and sustainable groundwater utilization. For electric pump sets, throughout almost the whole of India, charges are levied on a flat rate basis in proportion to the size/horse-power of the pump set. Such non-volumetric charging has only a very indirectly weak impact on actual water use (The World Bank 1999b). Moreover, in most areas power is supplied to the rural areas with a heavy subsidy element.

Moench (2003) maintains that much has been written on groundwater overextraction and water quality concerns in India but their real dimensions are difficult to evaluate objectively. Despite the apparent widespread nature of groundwater mining and pollution problems, the real extent may not be recognized since official statistics on the number of blocks where extraction is approaching or exceeding recharge may be misleading. There is great uncertainty over these estimates (Moench 2003). The average figure of water availability shows that the annual replenishable groundwater resources in India amount to about 430 BCM, and that the net withdrawal amounts to about 160 BCM per year. Based on these numbers and averages, this does not seem to be a grave problem. But averages are deceptive and most water issues are largely local issues. At the local level a huge number of productive localities are already under severe groundwater stress.

Perceptions of widespread overextraction stem from two pieces of strongly suggestive data:

- The rapid growth in the number of pumps and power consumption related to agricultural irrigation.
- Clear evidence of substantial water level declines in selected areas along with data suggesting that such areas are increasing rapidly.

TABLE 7.16 Categorization of Blocks/Talukas/Watersheds as Overexploited and Dark/Critical

		Number of districts	Number of assessed units (districts/blocks/taluka/mandal)	Overexploited		Dark/Critical	
				Number	Per cent	Number	Per cent
1	Andhra Pradesh	22	1231	219	17.79	77	6.25
2	Arunachal Pradesh	3	3	0	0.0	0	0.0
3	Assam	23	134	0	0.0	0	0.0
4	Bihar	42	515	0	0.0	0	0.0
5	Chhattisgarh	16	146	0	0.0	0	0.0
6	Delhi	9	9	7	77.78	0	0.0
7	Goa	3	11	0	0.0	0	0.0
8	Gujarat	20	223	31	13.90	12	5.19
9	Haryana	17	113	55	48.67	11	9.73
10	Himachal Pradesh	12	5	0	0.0	0	0.0
11	Jammu & Kashmir	14	8	0	0.0	0	0.0
12	Jharkhand	13	208	0	0.0	0	0.0
13	Karnataka	19	175	65	37.14	3	1.71
14	Kerala	14	151	5	3.31	15	9.93
15	Madhya Pradesh	45	312	24	7.69	5	1.60
16	Maharashtra	29	318	7	2.20	1	0.31
17	Manipur	6	7	0	0.0	0	0.0
18	Meghalaya	5	7	0	0.0	0	0.0
19	Mizoram	3	22	0	0.0	0	0.0
20	Nagaland	7	7	0	0.0	0	0.0
21	Orissa	30	314	0	0.0	0	0.0
22	Punjab	17	137	103	75.18	5	3.65
23	Rajasthan	32	237	140	5.91	50	21.10
24	Sikkim	4	1	0	0.0	0	0.0
25	Tamil Nadu	27	385	142	36.88	33	8.57
26	Tripura	3	38	0	0.0	0	0.0
27	Uttar Pradesh & Uttaranchal	74	820	39	4.76	13	1.59
28	West Bengal	16	269	0	0.0	1	0.37
29	UTs		18	2	11.11	0	0.0
All-India		516	5723	830	14.50	226	3.95

Source: Central Ground Water Board (2006).
Note: Central Ground Water Board (2006). Unit of assessment: Mandals—Andhra Pradesh; talukas—Maharashtra, Gujarat, Karnataka, and Goa; districts—Arunachal Pradesh, Assam, Meghalaya, and Nagaland; state—Sikkim; districts (Valley)—Jammu and Kashmir and Himachal Pradesh and; islands—Lakshadweep. Rest of the states—blocks.
Overexploited: >100%; Dark: >85%—<100%

The situation on the ground indicates that official figures are probably underestimates (Moench 2003). The number of energized pumps, for example, is estimated based on loan and subsidy applications through NABARD. Loans and subsidies are not given in areas that have been declared 'dark' due to groundwater overextraction. However, well drilling continues based on private sources of finance—such wells are often not captured in official statistics and the numbers may be large. In Mehsana district of Gujarat, for example, estimates indicate that some 2,000 wells may be being drilled annually despite the region having been 'dark' for more than a decade (Moench and Kumar 1995). Further, until recently, there was substantial political pressure at the local level to ensure that regions were not declared overexploited or critical. Subsidies and votes tend to go together in all parts of the world and in India too this may have had an impact on estimates of groundwater extraction (Moench 1994)

For India as a whole, over 14 per cent of all blocks (referred to in Table 7.16) are either overexploited or critical, a number of which is expected to reach 60 per cent in just 25 years time, according to Briscoe (1996). A major problem of water table depletion is the deterioration in quality which has a large impact on the health of large sections of the population which heavily depends on groundwater. In Gujarat, groundwater provides most domestic and more than three-quarter of the irrigation water. Overextraction has caused the water table to fall by as much as 40 to 60 metres in many places, the yield of wells has decreased, cost of water pumping has increased, and in many cases wells are being abandoned. Groundwater mining in Gujarat and Rajasthan has resulted in fluoride contamination particularly endangering the poor in these areas.

Most discussions on groundwater overdraft emphasize the distinction between economic depletion (that is, falling water levels make further extraction uneconomic) and the actual dewatering of the aquifers (Moench 1992). Aquifers are depleted in an economic sense long before there is any real threat of their being dewatered. The Gangetic basin may have 20,000 feet of saturated sediment but from an agricultural perspective only the top few hundred feet are economically accessible for irrigation. Particularly, wells owned by small/marginal farmers are often shallow—only a few tens of feet deep. Putting this in the context of poverty and famine, falling water tables will first exclude the poor—those who cannot afford the cost of deepening wells. This may happen long before they affect the availability of water to wealthy farmers and other affluent users (Moench 1992).

Moench (2003) indicates that the impact of this would tend to be particularly pronounced during drought periods when a large number of small/marginal farmers could simultaneously lose access to groundwater when their wells dry up. During non-drought periods, water-level declines would undermine the economic position of small/marginal farmers forcing them onto already saturated unskilled agricultural and urban labour markets. The food security crisis in both these situations may be through the economic route rather than because of food grain availability per se.

A region where one of the most extensive overextraction of groundwater has taken place in the country is north Gujarat. Tube well depths have often crossed 1,000 feet in this area. Results from a recent study by Gandhi and Roy (2009), indicate that hardly any institutional change has taken place so far to deal with the situation. Cooperatives and partnerships of farmers exist and these do make an assessment of the quantity of water available and do contribute to more equitable distribution of the water among members. However, no attempt has been made to price the water according to its scarcity value and use. The members are aware that the activity of the institution is depleting groundwater in the village, but no effort is made by the institution to monitor or control the depletion and environmental harm. Equity is being looked at but scarcity and environmental harm/depletion are not being addressed.

Groundwater Quality Problems

Sharma and Kumar (2005) indicate that problems of water quality are emerging even in areas, such as the water-rich Krishna delta in Andhra Pradesh, a highly productive area known for its high crop yields. Due to insufficient supply of canal water, farmers' dependence on groundwater for irrigating crops has increased manifold during the last decade. The existing groundwater salinity problem has worsened as a result of unplanned groundwater development and extraction. An in-depth analysis of the hydro-geologic conditions was done through a two-dimensional cross-sectional model, and the simulations showed that the increase in groundwater salinity in the region (except close to the coast) was not due to saltwater intrusion from the sea but because of saline water intrusion from existing saline zones into freshwater zones, because of groundwater extraction.

Babaria et al. (2005), examined the quality of irrigation groundwater in the water scarce Saurashtra region of Gujarat. A survey of irrigation water in the seven districts of Saurashtra was undertaken and 169 underground well/tube well water samples were collected from the cultivate fields. Survey data indicated a range of Electrical Conductivity (EC) from 0.5 dS m^{-1} to 23 dS m^{-1}. Overall mean value (5.87 dS m^{-1}) was considerably higher than the critical value, and this was indicative of potential development of saline soils in these districts. By district, the highest mean value of pH 9.8 was recorded in Amreli and the lowest mean value of pH 6.7 was recorded in Junagadh. The overall mean value of SAR was 10.13.

The Efficacy of Water Institutions (Laws and Policies) in Managing Groundwater Challenges

According to the Indian Constitution and laws, groundwater is in the private regime in India, and the rights to groundwater are vested with the landowner. When a sale or purchase of land takes place, these rights are transferred with the rights to land from one owner to another. Besides this, under the Constitution water is a 'state subject' in India and is therefore under the jurisdiction and control of state laws and policies, with very little control of the federal/central government, except in the case of inter-state water disputes which are referred to it.

The Ministry of Water Resources, Government of India had proposed a new bill on groundwater control and regulation in 1970 which was revalidated in 1992 and circulated to all state governments. Some of the major elements of this included powers to notify specific areas for control and regulation of groundwater development, requiring grant permissions to extract and use groundwater in the notified areas, registration of existing users in the notified areas, prohibition of carrying on sinking wells in the notified areas, and so on. But it failed to get accepted and take off. There was no clause for involving users or user groups in the management structure.

Given this status of groundwater in the country, the Government of India recently brought out a National Water Policy in 2002 (Ministry of Water Resources 2002b: 4) which also covers groundwater resources. A few provisions of the policy are:

- There should be a periodical reassessment of the groundwater potential on a scientific basis, taking into consideration the quality of water available and economic viability of its extraction.
- Exploitation of groundwater resources should be so regulated as not to exceed the recharging possibilities, as also to ensure social equity. The detrimental environmental consequences of overexploitation of groundwater needs to be effectively prevented by the central and state governments. Groundwater recharge projects should be developed and implemented for improving both the quality and availability of groundwater resources.
- Integrated and coordinated development of surface water and groundwater resources and their conjunctive use should be envisaged right from the project planning stage and should form an integral part of project implementation.
- Overexploitation of groundwater should be avoided especially near the coast to prevent ingress of seawater into sweet water aquifers.

However, the National Water Policy as well as other such policy statements have largely remained on paper and not been translated into action (Jeet 2005). This appears to be primarily because the policies are not supported by the required institutional framework of laws, structures, and operational mechanisms. As indicated earlier, the legal and absolute right to groundwater rests with the landowner. Transferability of ownership independent of land is not defined. Tying water rights to land rights has major implications for access to groundwater and the distribution of benefits of water use, and it also constrains the potential for intersectoral allocation. The regulation of groundwater extraction suffers from major gaps (Briscoe and Malik 2006). Apart from a limited Act for the Chennai metropolitan area, 1987, a Bill in Gujarat, 2001, and the one passed by Maharashtra for protecting rural water supply, 1993, none of the states in India have addressed groundwater rights. However, indirect attempts have been made for controlling groundwater extraction.

These are, for example, through credit rationing by NABARD based on the degree of aquifer development, curbing new power connections to bore wells, and time restrictions on electric power supply. The present environmental legislations and regulations are also weak in addressing the environmental impact of groundwater utilization (Briscoe and Malik 2006).

The Central Ground Water Board (CGWB) has prepared a model legislation for groundwater regulation. This has been circulated to state governments and has undergone many revisions. The present version mainly emphasizes regulation, including management and overdraft regulations. These versions, however, contain no provision for ensuring the participation of the local population in the management or in the regulation (Jeet 2005).

A major institutional reform would be establishing tradable private property rights in groundwater. This could also empower communities to have rights over the groundwater that they manage, and address issues, such as efficiency, equity, and sustainability (Kumar 2003). However, bringing about such reforms in water rights would be a complex process because such rights may not always be mutually exclusive (Saleth 1996). If appropriate legal, institutional, and policy regimes exist, local user groups/organizations can emerge in problem areas with support from external agencies, such as NGOs (see Boxes 7.1 and 7.2 for some insights into independent initiatives). Some of them can help recognize the rights of individuals and communities over groundwater, and establish tradable private property rights. The present institutional arrangements in

Box 7.1
Groundwater Recharge in Khopala

Village Khopala is located in the Bhavnagar district of Saurashtra in Gujarat. It is a medium sized village with about 1,200 households and a population of approximately 6,500. The village community comprises of a mix of caste groups, including Patel, Bharwad, Harijan, Rajput, Khumbhar, Brahmin, Muslim, Vaghri, Koli, and a few others.

The village regularly faced acute water shortage due to low and erratic rainfall. Recently it received only 7 inches of rainfall. In the adjoining district of Rajkot, village Rajsamadiyala had dramatically improved its water availability by building check dams. Impressed by this, in 1998 Mathurbhai Savani, who belonged to Khopala village but was now a businessman in Surat, decided to motivate the villagers about the usefulness of water conservation methods, including the construction of check-dams. Savani spent a great deal of time with the villagers and convinced them about the importance of water conservation for easing the availability of water. He took a group of 50 villagers to Rajsamadiyala village at his cost and showed them the benefits of check dams. This motivated them greatly. The villagers realized the importance of water conservation and formed a village committee (*samiti*) for water conservation. The committee had broad representation and included many different caste groups.

Committee members surveyed the entire village area and identified about 200 locations suitable for constructing check dams. They also identified 16 sites for development for the purpose of farm ponds. There was also a big pond site on the government land, which could be developed and converted into a much better pond. After the survey, the committee had a meeting and took important decisions including:

- Construction of 200 check dams
- Construction of 16 farm ponds
- Collecting a contribution from each farmers @ Rs 1,200 per hectare
- Purchasing 5 acres of land from farmers in and around the big village pond for development
- One person from each family in the age group of 20 to 40 years should contribute labour for development work for 60 days
- Nobody should lift water from the village pond for irrigation purposes
- No tree felling in the village, and if anybody violated this, he/she should pay a penalty of Rs 1,000
- Bullock cart roads were earmarked for accumulation and channelization of water towards the check dams
- They decided to take 3 metre wide patches of land from both sides of these roads to expand the channel to provide room for water accumulation and shift the road to the side
- Any tube well of depth greater than 90 feet would not be allowed to function in the entire village area including the farms

(*contd.*)

Box 7.1 (*contd.*)

Later they also came to know about a government scheme supporting construction of check dams. Under this the government contributes 90 per cent of the total cost and the rest is to be borne by the villagers. The government's share is routed through NGOs. Since the construction of check dams was not planned with the help of an NGO nor had they made any application to the government, this would take time. After extensive deliberations, the samiti decided to go ahead with the construction of check dams without the help of the government and through their own contributions. They decided to do this before the 1999 monsoon season. At this juncture, Savani came up with the proposal of a 75:25 scheme, in which the villagers would have to raise only 25 per cent and he would make arrangements for 75 per cent of the costs through donations. The samiti agreed to his suggestion and began collecting the required funds at the rate of Rs 1,200 per hectare from each and every farmer. About 95 per cent of the farmers contributed (900 farmers) their share (*lokfalo*) accumulated to approximately Rs 36 lakh (1 lakh=100,000). And as promised, Savani raised a contribution of Rs 79 lakh. Thus the total fund available for the construction of check dams reached Rs 115 lakh.

On 19 December, 1998 the samiti started the construction of check dams and repair work of the ponds. Before the 1999 monsoon season (June), they had constructed 200 check dams. Besides, they had enlarged and repaired the village pond, increasing its size from 5 to 10 acres. They had also made 16 new farm ponds in the village, ranging in area from 0.5 bigha to 5 bigha (4 bigha=1 ha). Among the 200 check dams, 80 were of about 5 metres in length, 100 were of 5 to10 metres, 17 were of 10 to 20 metres, and 3 dams had a length of more than 20 metres. The total cost incurred for all these was Rs 135 lakh. So the samiti ended with a deficit of Rs 20 lakh. However, they were not deterred by the deficit in completing the work. They borrowed this amount from well-to-do farmers and traders.

In the meantime they came to know about a scheme of the Forest Department for the construction of check dams. The samiti approached Forest Department officials, and explained their current position of a deficit of Rs 20 lakh. The officials inspected the check dams made by the villagers, and out of 200 check dams, they offered help for 30–35 check dams which amounted to Rs 20 lakh. This was paid in August-September, 1999. Thus, the samiti could meet all the costs and clear the debts.

After the check dams were completed in June1999, the monsoon started. Immediately after the onset of the monsoon the results started becoming visible. Before the check dams were constructed all the open wells (about 450) in the village had been dry. In the 4 tube wells, water was available only at a depth of 200 feet or more. Immediately after rains the open wells were seen starting getting recharged. There were about 40 open wells which had been completely abandoned. They were cleaned. These wells were also recharged. By the end of 1999 all the open wells in the village had been recharged fully. Water became available at a depth of only about 40 feet. By the end of 2003 over 60 open wells had been newly constructed. The owners of the 4 tube wells discontinued their use and began to depend only on their open wells. If anyone wanted to sink a tube well even for drinking purposes, they were allowed to go only up to a depth of 90 feet. It was estimated that there was an almost 4-fold increase in the availability of water for irrigation. The samiti also distributed 10 tree saplings to each farmer in 1999 to grow on their farm boundaries. In 2003, Savani inspected the tree saplings, and those farmers who had grown the maximum number of sapling were given rewards.

India which involve central, state, and local institutions, and both formal and informal structures, are unable to bring about water allocation, planning, and management on a comprehensive or scientific basis.

Bold steps have been taken by many countries in the face of similar challenges that India is facing concerning groundwater ownership. In the early 1980s the legislatures of the American arid states of Arizona and New Mexico replaced the common law/rule of absolute ownership of groundwater, with a government-administered permit system of groundwater extraction (The World Bank 1999b). The legislature of the Australian state of Victoria did the same thing with the 1989 Water Act. In England and Wales, government-administered licensing requirements were superimposed on the existing riparian rights in groundwater under the 1963 Water Act. The Spanish legislature passed legislation in 1985 whereby all hitherto private groundwater resources became the public property of the state. Italy's parliament passed legislation in 1994 vesting all private water resources, including, in particular, groundwater in the state. These legislations effectively curtailed the significant attributes of land ownership, such as the right to sink a well, and the right to extract any amount of groundwater from beneath one's own land (The World Bank 1999b).

Box 7.2
Sodhala Tube Well Partnership and Water Markets in Kansa Village

The concept of partnership in tube well irrigation system came into existence in Kansa village in 1962. The declining water table, high cost of construction of the tube wells at the individual level, and their low life-span were the major reasons behind the start of this innovation in irrigation. Kansa village is in Visnagar taluka of Mehsana district in Gujarat. It is a large village of about 2,300 households and a population of about 12,000. The village community has many caste groups, including Patel, Thakor, Rajput, Brahmin, Vaghri, Raval, and Harijan. Agriculture and dairying are the major economic activities and the major crops are wheat, mustard, cotton, and castor. The minor crops are *jeera* (cumin), *variyali* (fennel), *methi* (fennugreek), *sava*, chichory, *isobgul*, *bajri* (pearl millet), *guar*, *moong* (green gram), sesamum, paddy, *jowar* (sorghum), *banti,* and fodder crops.

Five farmers of Kansa village—Ramanbhai Patel, Keshavlal Patel, Ishwarbhai Amthibhai Patel, Senthabhai Madhavlal Patel, and Babubhai Keshavlal Patel —got together to form a tube well partnership called the Shodhala Tube-Well Partnership. They invested in and constructed a tube well of 180 feet depth and installed a 30 HP electric pump in it. The partners shared the capital investment and also the operating cost and income from the sale of water equally. Apart from their own use, they earned a profit by selling water to fellow farmers. In the early 1960s they got power supply for 20 to 22 hours in a day. From the late 1960s, the power supply became erratic and it was available for only 10 to 14 hours a day. As a result, the water pumped was not sufficient to irrigate their lands as well as the land of other farmers. In the early years the average profit was about Rs 50,000 per year. But over the years, with the power supply problem and declining water discharge from the well, the profits declined.

Ultimately the tube well enterprise failed in 1975, and the partnership then constructed a new tube well. This time the necessary well depth increased to 300 feet and it was operated with a 45 HP pump. They also increased the number of partners from five to 25. The partnership share varied from 1 to 5 per cent. This tube well remained operational until 1990 when 40 farmers were made partners with partnership shares ranging from 1 to 5 per cent. The partners were from the Patel and Thakore communities. They constructed another tube well whose depth was 480 feet and it had a 75 HP pump. This tube well was in good working condition until recent times. In last few years the enterprise and the farmers have faced acute power supply problems. The power supply is available only for 6 to 7 hours a day and there are high voltage fluctuations. The supply timings are also very irregular. Because of this erratic nature of power supply, the pump needs repair 2 to 6 time a year. Each time the repair costs come to around Rs 10,000. In recent years, the partnership has been able to provide irrigation to only about for 85 bighas of land (4 bighas = 1 ha).

Though, the Shodhala Tube well Partnership is an informal unregistered partnership, it has evolved an institutional structure. It has a general body of partner members, which meets every year. Decisions, such as the share of water to be made available to each member in the forthcoming season are taken in this meeting. This water share is based on various factors, including the contribution share of the member in the partnership, the expected power supply availability situation, and the expected available water discharge from the tube well. Typically, each partner is expected to use a minimum of Rs 500 worth of water, and even if he does not use it, he is required to pay Rs 500 to the partnership. This compulsory collection helps to meet fixed costs, including the fixed electricity charges for the pump. Ramanbhai Keshavlal Patel is the founder member of this partnership and is its leader. He has managed the partnership for many years. For his role and work he is paid Rs 20,000 per year. The partnership has to pay a fixed flat rate electricity charge @ Rs 500 per HP of the pump per year and the electricity bill is received every six months.

The enterprise has evolved a system of charging partners and other farmers for the water. The water output of the tube well gets divided into three equal parts and comes out in three separate outlet pipes. The output of each pipe is called one unit output flow, and locally it is called one '*reila* or 'stream'. The basis of pricing is per reila per hour and the present price is Rs 35 per reila per hour in cash. If the discharge from the well is good then all the three reila are brought out and used to irrigate separate fields or else fewer 'reila' are brought out. From 'reila', it typically takes 8 to 9 hours to irrigate one bigha of land for the first irrigation. Subsequent irrigations may require only 6 hours. As mentioned earlier, the charge is Rs 35 per reila per hour in cash, or alternatively, in kind per bigha irrigated for some crops. The current crop-wise pricing is given in the Table 7.17. For payments in kind, the produce is collected at the end of the season. The general body identifies a trader during its meeting and the produce is sold through him. The produce may also be stored for some time to get a better price. The profit/loss is calculated at the end of the year and this is divided among the partners based on their share in the partnership.

TABLE 7.17 Pricing of Water: Crop-wise Charges and General Irrigation Needs

Item/Crop	*Mustard*	*Cumin and fennel*	*Wheat*	*Castor*
Water charges in cash (Rs 35 per reila per hour) or in kind	80 kg mustard per bigha	Rs 35 per reila per hour	240 kg wheat per bigha	Rs 35 per reila per hour
Number of irrigations typically required by the crop	4	4	6	5 to 8

The partnership faces many problems. A major problem is the limited power supply, often for only a few hours a day. Another problem is the fluctuation in power supply which damages the motor and increases maintenance costs. A serious problem is the decline in the water table and therefore decreasing outputs from the wells. The capital cost of the construction of wells is increasing because of the increasing water table depth as well as the increase in construction and equipment costs. Some rough figures reported by the farmers are given in the table below. Besides, there is an increasing risk since the outcome of the drilling of tube wells is uncertain, adding to the cost as well as the risk. Further, operating costs are rising and the wells often fail early—they have a shorter life-span. With rising costs, risks, and scarcity, getting the involvement, contribution, and cooperation of the farmers is becoming more difficult and challenging.

TABLE 7.18 Approximate Depth of the Water Level, Wells, and Well Cost Over the Years

Year	*Water level (ft)*	*Well depth (ft)*	*Cost (Rs)*
1963	40	100	50,000
1970	90–100	250	1,00,000
1980	250		
1990	350	700–800	
2000	400		
2003	500	1,000	10,00,000

CONCLUSIONS AND POLICY IMPLICATIONS

Groundwater has grown in importance to occupy a dominant place in India's agriculture, food security and water supply. It has become the main source of growth in irrigated area and is now critical to food security. Groundwater management is, however, heading for a crisis in India and needs urgent attention and understanding.

It is clearly established that having irrigation water improves agriculture, and further, in-depth research finds groundwater to be a superior source of irrigation compared to surface water. It is associated with better yields, input use and profitability. This is mainly because it offers better control over water availability and use to the farmers. Researchers find that farmers owning wells generally achieve the highest yields, while those purchasing water from well owners achieve yields higher than those dependent on canal irrigation alone. Yields in groundwater irrigated areas are found to be higher by one-third to one-half as compared to those from areas irrigated by surface sources. Well irrigation is also associated with higher cropping intensity, higher cash input expenditure and higher gross income per acre. Increase in groundwater irrigation is also closely associated with a reduction in the risk and variation in production.

Assessments show that India has a huge groundwater resource but its availability and status vary substantially between basins, states, and areas. 40 per cent of the groundwater resource is in the Ganga basin alone, and no other basins even crosses 10 per cent. Given this variation, the management of groundwater would need to be different in different areas. Overall, groundwater extraction has increased dramatically in the six decades all over India since independence. Official Indian statistics and projections all indicate rapid growth in the area irrigated from groundwater, the number of wells, and the number of energized pump sets, and data from the World Bank-GOI reviews also show the same.

The state-wise profiles bring out an alarming picture. The level of groundwater development is already as high as 141 per cent in Punjab, 111 per cent in Rajasthan and 105 per cent in Haryana. This is followed by Tamil Nadu at 81 per cent, Gujarat at 70 per cent, and Uttar Pradesh/Uttarakhand at 65 per cent. Further, these figures hide the highly skewed intra-state distribution. Assessment by talukas/blocks/assessment units indicates that in Rajasthan, over 80 per cent of the blocks/assessment units are overexploited, dark or critical, closely followed by Punjab at 78.8 per cent, Delhi at 77.8 per cent, as well as Haryana, Tamil Nadu and Karnataka at 58.4, 45.5 and 38.9 respectively, and Andhra Pradesh and Gujarat are above the national average in overexploitation.

There is rapid growth in pump numbers and power consumption related to irrigation and clear evidence of substantial water level declines. Information suggests that declines are increasing rapidly even in the areas declared 'dark'. There is also often substantial political pressure at the local level to ensure that regions are not declared overexploited or critical. This could be affecting the groundwater status statistics and the official figures may be underestimates.

There is an urgent need to tackle overexploitation of groundwater in the country. The measures may range in nature from informal to formal, individual to institutional/legal, and voluntary to compulsory. At an informal level, awareness about groundwater overexploitation and its consequences needs to be greatly increased through extension and publicity campaigns. Groups or associations of farmers may be formed to monitor and manage groundwater. These may be built over existing water users groups/associations/cooperatives or farmer bodies of other kinds. A government department initiative to measure the groundwater level/situation (already existing in some areas) on a monthly or quarterly basis extensively across blocks/villages is required along with reporting and dissemination of this information through the above mentioned means and bodies. Since electric pumps are extensively used to pump the water, controlling the availability of electricity supply for operating pumps can go a long way in reducing overexploitation. This has been successfully tried in parts of Gujarat. Metering and charging of electricity at the real economic price also needs to be implemented.

Other direct measures would include restricting the number of tube-wells through licensing or through imposing institutional credit restrictions. Pumping of water can also be restricted through installation of water meters on tube-wells as done in many developed countries. Overall, new legislation is required to control groundwater exploitation, and a constitutional amendment separating the right to groundwater from the right to land would help provide the necessary foundation for stronger laws and institutional controls.

Since agriculture is the largest user of water, accounting for over 80 per cent of the water use, improvement in the efficiency of water use in agriculture can go a long way in alleviating the supply-demand imbalance and tackling the overexploitation of groundwater. Frequent flooding of fields to irrigate is extremely inefficient especially when no proper assessment of the soil moisture and the crop water need is done, and the fields are poorly leveled. Promotion of alternatives such as irrigation through furrows, drip irrigation, and sprinkler irrigation can greatly improve water use efficiency and even these should be done after assessment of soil moisture and critical stages of crop water need. Good land leveling can also go a long way in reducing farm water need. Other conservation measures such as mulching can also help.

To signal the scarcity of water, formal and informal controls and proper pricing of water is a must. If water is expensive, farmers will use it more efficiently. Pricing should be done by crop, and high water charges should be there for high water using crops such as sugarcane, rice and banana. Restrictions on the dates of planting for crops such as rice can also help, as has been done in Punjab. Avoiding the extremely hot weather in May-June for planting rice can greatly reduce water need and improve water use efficiency. This would be helped by developing and recommending the appropriate crop varieties. On these lines, the development of varieties which are drought resistant and have better water use efficiency would also help substantially.

Aquifers are depleted in an economic sense long before they are dewatered. Often only the top few hundred feet are economically accessible for irrigation. Further, wells affordable to small/marginal farmers are often shallow and falling water tables will first exclude the poor long before they affect availability of water to wealthy farmers and other affluent users. This effect would to be particularly pronounced during drought periods when huge number of small/marginal farmers would simultaneously lose access to groundwater as their wells dry up. Depleted access forces them onto already saturated unskilled agricultural and urban labour markets. Thus both the poverty and the food security situation would be aggravated in these conditions through the economic as well as the food grain production route.

Institutional development such as the setting-up of elected and empowered water user associations is extremely important to improve the efficiency and equity in groundwater management. However, the ability of such institutions to implement control would be substantially enhanced by the separation of water rights from land rights, and putting water rights on a strong, separate and equitable basis. Apart from reducing overexploitation, increasing the recharge of groundwater through harvesting of rain and surface flows would prevent the dewatering of aquifers, and also greatly improve equity by making water available in the wells affordable to small and marginal farmers.

Deteriorating quality of the groundwater is another major problem and is substantially related to overexploitation in many areas—particularly with salinity, fluoride and other chemical toxicity problems which usually increase with water depth. However, other contaminations also need to be addressed. Regular testing of all sources of water which are being used for human consumption is a must in improving awareness, alertness and control. Creating alternative sources of water is a must where quality problems exist.

As indicated earlier, different approaches are required in different areas and so state governments and state policies need to play a very important role. In Eastern India, for example, which is in the Gangetic basin, there is a case for development of groundwater resources. Eastern India has the bulk of India's poverty and is largely rural, agricultural, flood-prone, with a high population density, and has had a slow pace of groundwater development. Increased density of wells can increase the welfare of the people through irrigation as well as through the powerful positive externality of working against water-logging and flood-proneness. Research indicates that pumping out of groundwater for irrigation in the dry season can create substantial capacity in aquifers to store flood and drainage water underground during the wet season, and this can mitigate floods by leading to as much as 50 per cent reduction in the monsoon flow of rivers. Thus, groundwater development can contribute to full realization of the agricultural potential of the eastern region and also be effective in reducing and preventing flood and water-logging conditions which are major threats in eastern India. However, safeguards are a must to foster planned development and prevent overextraction.

Legally, water is a state subject in India and groundwater is under the private regime. The rights to groundwater belong to the landowner. The rights to groundwater are transferred to anyone to whom the land is transferred. There is no limitation on how much groundwater a particular landowner can draw. This leads to a concentration of water ownership with the land and capital owners in India and a lack of control over the extraction of water. Legally separating land and water rights would be a fundamental step in better managing groundwater.

The present institutional arrangements in India involving central, state, and local institutions, and both formal and informal structures, are unable to bring about water allocation, planning and management on a comprehensive or scientific basis. Apart from immediate controls, a major institutional reform required is the establishment of specific private and community property right in groundwater preferably tradable property rights. This would also empower communities to manage groundwater better and address issues such as efficiency, equity and sustainability. Bringing about such reforms would be a complex process. But if appropriate legal, institutional and policy regimes exist, local user groups/organizations can emerge in problem areas with support from external agencies such as the government and NGOs, bringing better control and efficient use.

Many countries facing similar challenges have taken bold steps. The legislatures of the American arid states of Arizona and New Mexico replaced the common law/rule of absolute private ownership of groundwater, with a government-administered permit system of groundwater extraction. The legislature of the Australian state of Victoria has also recently made a similar change replacing the law/rule of absolute private ownership of groundwater, with an administered permit system of groundwater extraction. In England and Wales, a government-administered licensing requirement has been superimposed on the existing riparian rights in groundwater. In Spain, in 1985, all hitherto private groundwater resources became the public property of the state. In Italy legislation was passed in 1994 vesting in the state all private water resources, including, groundwater. These changes are leading to far better management of the groundwater resources in these countries. Similar changes are urgently required in India.

References

Babaria, N.B., M.S. Solanki, A.V. Ardeshana, and V.G. Barad (2005), 'Quality of Underground Irrigation Waters of Saurashtra Region', in N.C. Patel, A.R. Subbaiah, K.C. Patel, and J.C. Nandasana (eds) *Sustainable Management of Water Resources*, Himanshu Publication, New Delhi, pp. 144–5.

Barraque, B. (1997), *Groundwater Management in Europe: Regulatory, Organizational and Institutional Change. How to Cope with Degrading Groundwater Quality in Europe*, In: Proceedings of the International Workshop: 'How to Cope with Degrading Groundwater Quality in Europe' 21–22 October, Stockholm, Sweden.

Bhatia, Bela (1992), 'Lush Fields and Parched Throats: Political Economy of Groundwater in Gujarat', *Economic and Political Weekly*, Vol. 27, No. 51–52. pp. A142–A170.

Briscoe, J. (1996), *Water Resources Supply and Management Issues in Chennai (Formerly Madras)*, The World Bank, Washington DC.

Briscoe, John and R.P.S. Malik (2006), *India's Water Economy: Bracing for a Turbulent Future*. The World Bank, Oxford University Press, New Delhi.

Bunsha, Dionne (2002), 'Groundwater Capitalism in Gujarat', in *Tubewell Capitalism: Groundwater Development and Agrarian Change in Gujarat*, Navroz K. Dubashi, Oxford University Press.

Centre for Science and Environment [CSE] (1991), 'Floods, Floodplains and Environmental Myths', State of India's Environment: A Citizens' report No. 3, CSE, New Delhi.

Central Ground Water Board (2006), *Dynamic Groundwater Resources of India,* Ministry of Water Resources, Government of India, Faridabad.

Chambers, Robert, N.C. Saxena, and Tushaar Shah (1987), *To the Hands of the Poor: Water and Trees*, Oxford University Press, New Delhi.

Dains, S.R. and J.R. Pawar (1987), 'Economic Returns to Irrigation in India', Report prepared by SDR Research Groups Inc. for the US Agency for International Development.

Dhawan, B.D. (1982), *The Development of tube-well irrigation in India*, Agricole Publishing Academy, New Delhi.

——— (1985), 'Output Impact According to Main Irrigation Sources: Empirical Evidence from Four Selected States', Paper presented at the INSA National Seminar on 'Water Management: Key to Development of Agriculture', 28–30 April, New Delhi.

——— (1993), *Trends and New Tendencies in Indian Irrigated Agriculture*, Commonwealth Publishers, New Delhi.

——— (1995), *Groundwater Depletion, Land Degradation, and Irrigated Agriculture in India*, Commonwealth Publishers, New Delhi.

Dubash, Navroz K. (2002), *Tubewell Capitalism: Groundwater Development and Agrarian Change in Gujarat*, Oxford University Press, New Delhi.

Freeman, D.M., M.K. Lowdermilk, and A.C. Early (1978), *Farm Irrigation Constraints and Farmer's Responses: Comprehensive Field Survey in Pakistan*, Colorado State University, Fort Collins, Colorado.

Gandhi, Vasant P. and N.V. Namboodiri (2002), 'Investment and Institutions for Water Management in India's Agriculture: Profile and Behaviour', in D. Brennan (ed.), *Water Policy Reform: Lessons from Asia and Australia*, Australian Centre for International Agricultural Research (ACIAR), Canberra, pp. 106–30.

Gandhi, Vasant and Ashutosh Roy (2009), 'The Performance of Ground-water Institutions in India: Empirical Study', in Lin Crase and Vasant P. Gandhi (eds), *Reforming Institutions in Water Resource Management: Policy and Performance for Sustainable Development*, Earthscan, London, pp. 237–59.

Gandhi, Vasant and Suresh Sharma (2009), 'The Performance of Rain-water Harvesting Institutions in India: Empirical Study', in Lin Crase and Vasant P. Gandhi (eds), *Reforming Institutions in Water Resource Management: Policy and Performance for Sustainable Development*, Earthscan, London, pp. 260–80.

Gleick, P. and L. Nash (1991), *The Societal and Environmental Costs of the Continuing California Drought*, Pacific

Institute for Studies in Development, Environment and Security, Oakland.

Herdt, R.W. and T. Wickham (1978), 'Exploring the Gap between Potential and Actual Rice Yields: The Philippine case', in *Economic Consequences of the New Rice Technology*, International Rice Research Institute, Los Banos, Philippines.

Jeet, Inder (2005), *Groundwater Resources of India: Occurrence, Utilization and Management*, Mittal Publications, New Delhi.

Kahnert, F. and G. Levine (1989), *Key Findings, Recommendations, and Summary. Groundwater Irrigation and the Rural Poor: Options for Development in the Gangetic Basin*, The World Bank, Washington DC.

Kumar, Dinesh (2003), 'Demand Management in the Face of Growing Water Scarcity and Conflicts in India: Institutional and Policy Alternatives for Future', in Kanchan Chopra, C.H. Hanumantha Rao, and Ramprasad Sengupta (eds), *Water Resources and Sustainable Livelihoods and Eco-System Services*, Concept Publishing Company, New Delhi, pp. 97–131.

Meinzen-Dick, Ruth (1996), *Groundwater Markets in Pakistan: Participation and Productivity*, International Food Policy Research Institute, Washington DC.

Ministry of Agriculture (2010), *Agricultural Statistics at a Glance 2010*, Directorate of Economics and Statistics, Ministry of Agriculture, Government of India, New Delhi.

Ministry of Statistics and Programme Implementation (2010), *Infrastructure Statistics 2010*, available at http://mospi.nic.in/Mospi_New/upload/infra_stat_2010.htm last accessed on 25 February 2011.

Ministry of Water Resources (2002a), *Third Census of Minor Irrigation Schemes, 2000–01*, Ministry of Water Resources, Government of India, New Delhi, pp. 4, 13–15.

——— (2002b), *National Water Policy 2002*, Ministry of Water Resources, Government of India, New Delhi, p. 25.

——— (2007), *Annual Report 2006–7*, Ministry of Water Resources, New Delhi.

Moench, M. and D. Kumar (1995), 'Distinctions between Efficiency and Sustainability: The Role of Energy Prices in Groundwater Management', in A. Agarwal (ed.), *The Challenge of the Balance: Environmental Economics in India,* Centre for Science and Environment, New Delhi, pp. 305–9.

Moench, Marcus (1992), 'Drawing Down the Buffer', *Economic and Political Weekly,* Vol. 27, No. 13, pp. A7–A14.

——— (1994). 'Approaches to Groundwater Management: To Control or Enable', *Economic and Political Weekly*, Vol. 29, No. 39, 24 September, A135–A146.

Moench, Marcus (2003), 'Groundwater and Food Security in India', in Kamta Prasad (ed.), *Water Resources and Sustainable Development*: *Challenges of 21st Century*, Shipra Publications, Delhi, pp. 148–67.

Prasad, T. and I.D. Sharma (1991), 'Groundwater Development for Agriculture in Eastern India: Problems, Prospects, and Issues', *Future Directions for Indian Irrigation* R.M.-D.M., Svendsen, International Food Policy Research Institute, Washington DC, pp. 230–53.

Rao, C.H.H., S.K. Ray, and K. Subbarao (1988), *Unstable Agriculture and Droughts: Implications for Policy*, Vikas Publishing House, New Delhi.

Renfro, R.Z.H. (1982), 'Economics of Local Control of Irrigation Water in Pakistan: A Pilot Study', Fort Collins, Colorado State University.

Saleth, R.M. (1996), *Water Institutions in India: Economics, Law, and Policy*, Commonwealth Publishers, New Delhi.

Shah, Tushaar (2003), 'Groundwater Management: Synthesis of IWMI Research 1999–2003', International Water Management Institute (Draft), Anand, India.

——— (1993), *Groundwater Markets and Irrigation Development: Political Economy and Practical Policy*, Oxford University Press, Mumbai.

——— (2003), 'Wells and Welfare in the Ganga Basin: Public Policy and Private Initiative in Eastern Uttar Pradesh', in Kamta Prasad (ed.), *Water Resources and Sustainable Development*: *Challenges of 21st Century*, Shipra Publications, Delhi, pp. 393–415.

Shah, Tushaar and K. Vengama Raju (1988), 'Groundwater Markets and Small Farmer Development', *Economic and Political Weekly*, Vol. 23, No. 13. pp. A23–A28.

Sharma, Anupma and Sudhir Kumar (2005), 'Modelling and Management of Shallow Aquifer System in Krishna Delta', in N.C. Patel, R. Subbaiah, P.M. Chauhan, K.C. Patel, and J.N. Nandasana (eds), *Sustainable Management of Water Resources*, Himanshu Publications, New Delhi, pp. 148–55.

Singh, Chhatrapati (1991), *Water Rights and Principles of Water Management*, Indian Law Institute, N.M. Tripathi Pvt. Ltd., Mumbai.

Singh, Dalbir (2003), 'Groundwater Markets and Institutional Mechanism in Fragile Environments', in Kanchan Chopra, C.H. Hanumantha Rao, and Ramprasad Sengupta (eds), *Water Resources, Sustainable Livelihoods and Eco-System Services*, Concept Publishing Company, New Delhi, pp. 311–40.

Singh, K. (1995), 'Cooperative Property Rights as an Instrument of Managing Groundwater', in M. Moench (ed.), *Groundwater Law*: *The Growing Debate*, VIKSAT, Ahmedabad, Gujarat, pp. 61–82.

The World Bank (1998), *India—Water Resources Management Sector Review, Groundwater Regulation and Management Report*, The World Bank and Government of India (MoWR), Washington DC and New Delhi.

——— (1999a), *Groundwater Regulation and Management*, The World Bank and Allied Publishers, Washington DC and New Delhi.

——— (1999b), *Inter-Sectoral Water Allocation, Planning, and Management*, The World Bank and Allied Publishers, Washington DC and New Delhi.

Tsur, Y. (1990), 'The Stabilisation Role of Groundwater When Surface Water Supplies Are Uncertain: The Implications for Groundwater Development', *Water Resources Research,* Vol. 26, No. 5, pp. 811–18.

——— (1993), 'The Economics of Conjunctive Ground and Surface Water Irrigation Systems: Basic Principles and Empirical Evidence from Southern California 22', Department of Agricultural and Applied Economics, University of Minnesota.