Water crisis in India: Innovative Approaches and Policy Imperatives for Sustainable Management of Groundwater Resource[1]

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ABSTRACT

Irrigation has a prime role in Indian agriculture, as 40 percent of the cultivated area is irrigated and 70 percent of the irrigated area is devoted to food crops to meet the needs of the ever growing population. While surface irrigation has been stagnating, groundwater irrigation has been increasing. In 1998, the groundwater extraction was 38 percent, which increased to 58 percent in 2009. Policies towards electricity, credit, technological innovations in well exploration, extraction and use, demographic shifts, lucrative product markets and week groundwater institutions are contributing to over-extraction. Since four decades, groundwater extraction exhibited a trajectory of utilization, boom, growing scarcity and eventually bust with rapid fall in groundwater table in the hard-rock aquifers. This has forced several marginal and small farmers to shift to dryland agriculture. The ineffective institutions efforts of the governance to contain groundwater overdraft have proved in vain. The challenge is thus to frame effective institutions focusing on resource management rather than resource development. Thus far, supply side of groundwater is being addressed by the State through schemes such as watershed development, tank rehabilitation, while the demand side is inadequately dealt. Thus key actions are necessary for demand management on individual and community basis. The community based approach to regulate groundwater incorporating IWRM is by promoting user groups with technical support and training. Major policy changes on energy and technical aspects in accurate assessment of groundwater recharge and extraction, maintenance of isolation distance, quality pumpsets, information dissemination, implementation of the best practices and appropriate crop pattern are in order.

Keywords

Groundwater over exploitation, groundwater institutions, property rights, sustainability.

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PRELUDE

Irrigation has a prime role in Indian agriculture offering food security as 40 percent of the cultivated area is irrigated and 69 percent of the irrigated area is devoted to food crops to meet the needs of the ever growing population. Thus in tropical countries like India, irrigation plays a vital role in securing food for the masses. The other key inputs viz., high yielding varieties/seed and chemical fertilizer cease to realize their potential unless irrigation is assured. In addition, the supply of land is highly inelastic and the net sown area growth has almost stagnated and hence the future growth of agriculture productivity depends on efficient use of water and land resources. Irrigation has also greatly facilitated to diversify the cropping pattern towards high value crops. Irrigation not only improved the food security and economic conditions of a large number of farmers but also contributed immensely towards ensuring food security and alleviating poverty.

The surface water irrigation is dominated by reservoirs and canal systems where investment is borne by the public, while farmer does not bear any cost of infrastructure. In India, major and medium irrigation development were post-independence phenomenon, since a major chunk of investments in successive five year plans were devoted towards developing irrigation infrastructure. The surface irrigation projects are mainly managed by the state governments due to their huge capital investment requirements and the economies of scale in its operation and utilization. The irrigation department is in charge of managing canal networks and distribution of water. The surface water farmer is required to remit just the water charges as water rate. In several states, farmers do not remit the water rate / water charges for surface water, virtually treating surface water as a ‘free’ public good. Thus the surface water is highly subsidized in India not reflecting the scarcity value.

In North India, by and large protective irrigation is practiced, which enables to cover maximum area. In South India, productive irrigation is practiced with the aim of maximizing the productivity per unit of water. In South India excluding Kerala, tanks, canals and wells are all crucial for irrigated agriculture. Most of the canal systems are old and obsolete; hence over all efficiency of irrigation infrastructure is deteriorating (Gulati, 2005). Thus, irrigation sector is fraught with low revenue-high investment muddle and the associated environmental problems.

EMERGENCE OF GROUND WATER IRRIGATION

Though irrigation in India began with public funded surface irrigation systems, of late, groundwater has gained a prominent place in the irrigation map of India. With the onset of the green revolution in Indian agriculture, the demand for irrigation water increased manifold. Since, surface irrigation has not been able to meet the increased demand for agriculture and other uses, groundwater development has witnessed a remarkable progress. In the case of groundwater, the farmer necessarily contributes for groundwater well, pump set, electrical fixtures, conveyance pipes, and other accessories, including drip / sprinkler irrigation if any. In addition, farmers in most of the states do not pay for electricity to pump groundwater on pro rata basis.

Problem

In order to reap the benefits of high value agriculture, the landowners are recklessly investing on drilling wells especially in hard rock areas where there is no assured source of surface irrigation and pumping water infinitely without caring for its regeneration. This is a kind of "tragedy of commons" wherein every well owner tries to capture as much water as he can and deplete the resource. As groundwater is treated as a common pool resource, a user maximising his share will lower others' share. As groundwater level gets lowered, it rises costs for all, as they need to deepen their existing wells and require high capacity pumps. This is typical case of reciprocal negative externality associated with groundwater overexploitation. Due to progressive fall in the water table, groundwater scarcity is looming in many parts of peninsular India affecting not only food security but also the drinking water needs in rural areas. Thus, the real challenge is how to ensure the sustainability in groundwater use while discouraging over exploitation in a way that is economically efficient, equitable and administratively and politically viable. What type of institutional innovations, economic instruments and policies are required to address the issues of groundwater depletion is of topical concern.

Focus:

The present study examines the trends in the growth of irrigation covering the trajectory of well irrigation, the degree of over exploitation, causes and the consequences of groundwater over mining. In addition, the study also addresses the critical management gaps and the appropriate institutional and corrective policy instruments to overcome the water crisis.

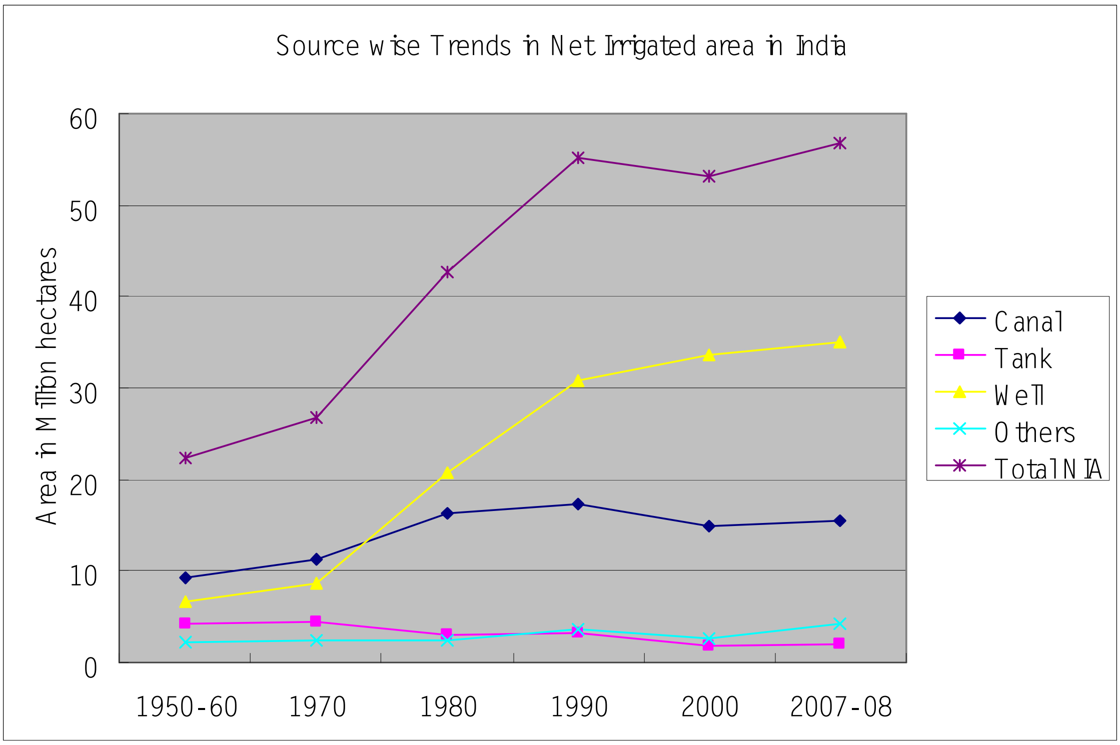
1. TRENDS IN SOURCE WISE GROWTH OF NET IRRIGATED AREA IN INDIA

Currently, about 40 % of the total cultivated area is under irrigation. It has a net irrigated area of 54.68 million ha and a gross irrigated area of 75.14 million ha, the largest in the world. Area under canal irrigation doubled from 8.3 ml ha to 17.4 ml ha between 1950 to 1990, while tank irrigated area declined from 4.2 ml ha to 3.3 ml ha during the same period. After 1990, the growth in the surface irrigated area has stagnated and declined while tank irrigation is shrinking and net irrigated area is increasing because of groundwater irrigation. On the contrary, the area under ground water irrigation has increased massively by five folds from about 6.6 ml ha to about 35 ml ha during the same period surpassing the flow irrigation (Fig 1). One of the prominent reasons for the decline in tank irrigation is the disappearance of village institutions that were managing the tanks, followed by heavy siltation reducing their live capacity. Similarly, the canal irrigation has stagnated and declining after 1990's due to several reasons which include: 1) Economic and environmental constraints for further physical expansion. 2) Irrigation water is highly subsidized not reflecting the scarcity value of water and the revenue generation from water rates has been abysmally low, hence poor maintenance leading to deterioration of infrastructure 3) The crop pattern in the flow irrigation is dominated by low value and high water requirement and not responsive to precision irrigation, hence water use efficiency is low 4) Public investments have been decelerating on new projects as well as ongoing projects. These factors show that the supply augmentation has been severely affected. Since, surface irrigation is not able to meet the irrigation requirements especially in dry areas, there has been explosive development in the groundwater exploration and extraction under private sector for agricultural use leading to boom in groundwater use.

The growth rate analysis indicates that there has been impressive growth in the area irrigated by wells recording 3.6 % annual growth in the past five decades (table-1). However, the growth rate was much higher (5.21 %) during 1960 to 1990 compare to 1991 to 2007 (0.91 %). The growth in groundwater development has been decelerating in recent years, probably due to the fact that it has reached its limits for further development in most of the predominant well irrigated states. Further due to large scale failure of shallow wells, many small and marginal farmers are constrained to invest on deeper wells as it entail huge investments.

The canal irrigated area grew at the rate of 2.1% between 1960 to 1990 and thereafter, it has been decelerating at -0.62 % per annum. Overall, canal irrigation exhibited a growth rate of 1.1 % per annum. On the contrary, the tank irrigated area shown the negative growth rate. The growth in area under tank irrigation has decelerated at the rate of -1.5 % per annum from 1960 to 2008. The total net area irrigated recorded a growth rate of 2 % per annum for the period.

Fig1. Trends in source wise Net irrigated area in India



Source: Fertilizer Statistics, 2007-08

Table-1. Trend in Growth rate of net irrigated area (CGR? Pl indicate)

Source	1960-90	1991-2007	1960-2007
Canal	2.1	-0.62	1.1
Tank	-0.79	-2.75	-1.5
Wells	5.21	0.91	3.6
Others	1.5	0.89	1.27
Net Irrigated area	2.7	0.16	1.97

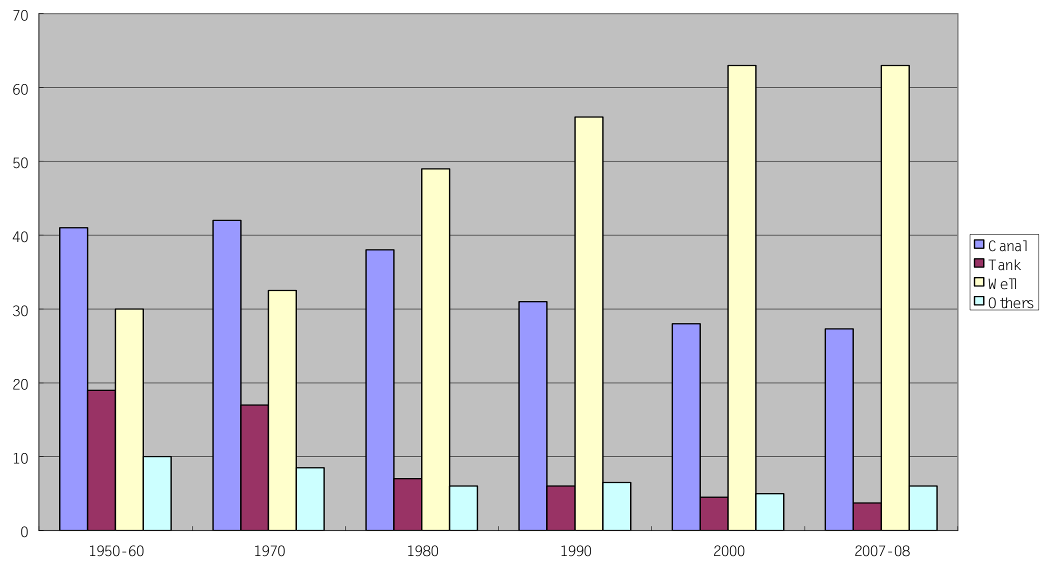


Fig 2 Share of Net Irrigated area by source

Changing Share of net irrigated area by source

The trends in percentage share of net irrigated area by source in the country indicates that canal irrigation share has been expanded from 1960 to 1980's accounting over 41 % and thereafter it has stagnated and falling (Fig-2). While the tank irrigated area has drastically plummeted from 19 % in 1960 to just 3 % in 2007. On the contrary, the well irrigation share has triggered from 29 % in 1960 to 61 % in 2007. Currently, 40 % of the cultivated area is under irrigation compared to 28 % during 1980's. Of the total net irrigated area, canal irrigated area accounts for 33 %, while tank irrigated area constitutes around 6 % and groundwater contribute 61 %. The food crops occupied 69 percent of the irrigated area, and the remaining 31 percent being under non-food crops.

Groundwater availability and Extraction

According to the Planning Commission's Expert Committee Report, the net annual groundwater availability is around 399 BCM. It is estimated that the existing functioning wells in the country are extracting about 231 BCM of water. Of this, over 92 % withdrawals is towards agriculture and the remaining is accounted for by domestic and industrial use. The availability of groundwater is unevenly distributed across different regions of the country. It can be seen from table 2, that in Indo-Gangetic and Brahmaputra plains, ground water potential is very high; such areas can support large scale development. In peninsular India and hilly states, however, groundwater potential is extremely low.

Table 2: Coverage and Potential of Ground Water Systems in the Country

System	Coverage	Groundwater Potential
Unconsolidated formations - alluvial	Indo-Gangetic, Brahmaputra plains	Enormous quantities up to 600 m. High rain fall and hence recharge is ensured. Can support large-scale development through deep tube wells
	Coastal States	Reasonably extensive aquifers but risk of saline water intrusion
	Part of desert area- Rajasthan and Gujarath	Scanty rainfall. No recharge. Salinity hazards. Availability at great depths
Consolidated/semi-consolidated formations sedimentaries, basalts and crystalline developed due to weathering and fracturing. rocks	Peninsular	Availability depends on secondary porosity developed due to weathering and fracturing. Scope for availability at shallow depths (20-40 m)

		in some areas and deeper depths (100-200 m) in other areas. Varying yields
Hilly	Hilly States	Low storage capacity due to quick runoff

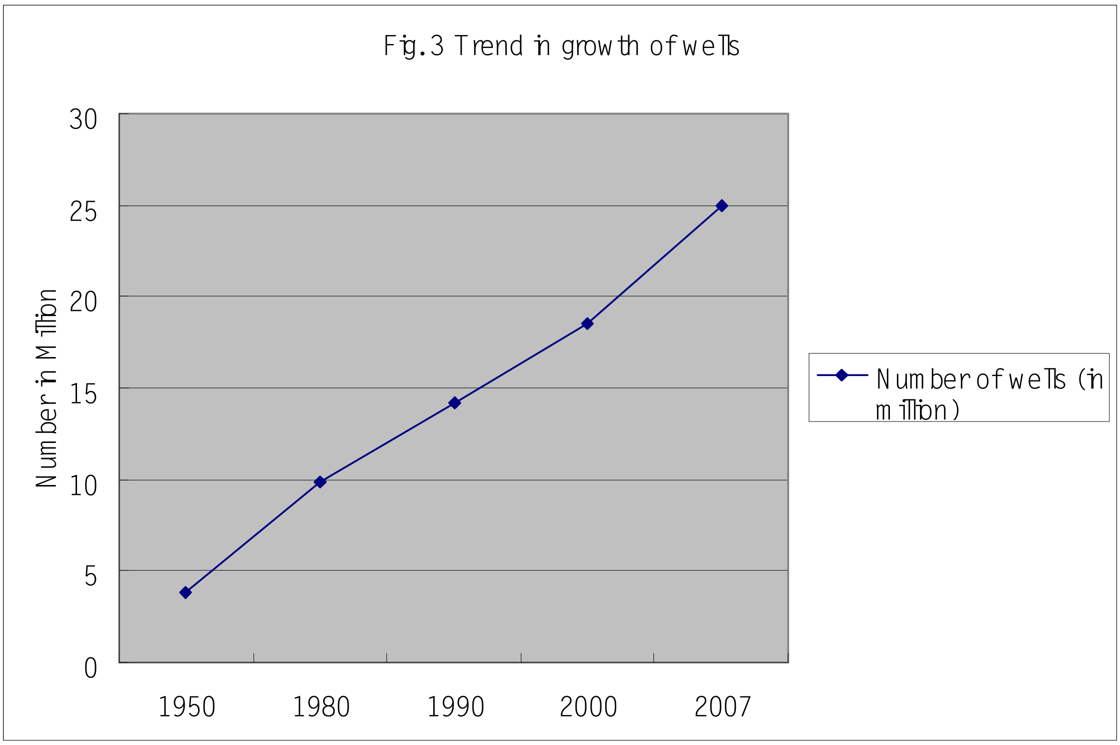
Source: Report of the expert group on Groundwater management and ownership, Planning Commission, Government of India, New Delhi-, Sept 2007.

2. GROUNDWATER DEVELOPMENT AT MACRO LEVEL SCENARIO

Groundwater has been lifeline in water- starved peninsular parts states of India playing a key role not only in improving food security but also largely responsible for bringing out diversification of farming systems in favor of high- value enterprises. Even today, in canal command areas rice and sugarcane crops are predominant, while in groundwater irrigated areas, high- value commercial crops like vegetables, fruits, and flowers have been dominating. Indeed, groundwater has turned the pockets of arid and semiarid areas into agricultural growth centres. Groundwater contribution towards stabilization of agricultural output and minimizing drought effects has been very crucial. The rapid growth of groundwater irrigation resulted in a boom, propelling rural and regional economic growth, and ensured livelihood and food security for the poor. Over half of the population of South Asia is now directly or indirectly dependent on groundwater irrigation for livelihood. Hence, it is crucial to sustain the groundwater boom experienced by these countries (David, 2004).

Currently, India is the world's largest groundwater user in terms of both absolute volume pumped and area irrigated as well number of users (Scott and Shah 2004). The trend in the growth of wells indicates that the number of wells increased from just 4 million in 1950's to 25 million by 2008 reflecting an explosive development in the growth of wells in the country (Fig-3).Correspondingly, there has been quantum jump in the area irrigated by wells from 6.6 million hectares to 35 million hectares during the period. Thus, there has been a sizeable expansion in the groundwater area irrigated and groundwater now is a primary source of irrigation surpassing the canal irrigation. The number of wells exhibited an over all growth rate of 3.25 % per annum from 1950 to 2007, which is almost on par with the growth rate of area irrigated by wells. However, there has been a spurt in the growth of wells after 1980's. There was a growth rate of 2.94 % per annum from 1950's to 1980's as against 3.56 % per annum from 1980's to 2007. Between 1960 and 1990, the area irrigated by wells grew much faster (5 %) than the growth rate in number of wells (3.3 %). On the contrary, the growth in area irrigated by wells has been much lower

(09 %) after 1990's, as compare to the growth rate in number of wells (3.3 %). This is an indication that in spite of increase in the number of wells, the area irrigated by wells is not growing in the same pace reflecting the physical scarcity of groundwater. It is also necessary to mention that along with growth of wells, the growth in well failure probability has also increased. Thus, if we weigh the growth of wells by the probability of well failure, then we can find the proper growth rate in the number of wells.



Source: a) Report of the expert group on Groundwater Management and ownership, planning commission New Delhi, 2007,` b) World Watch institute, Washington DC, 2009

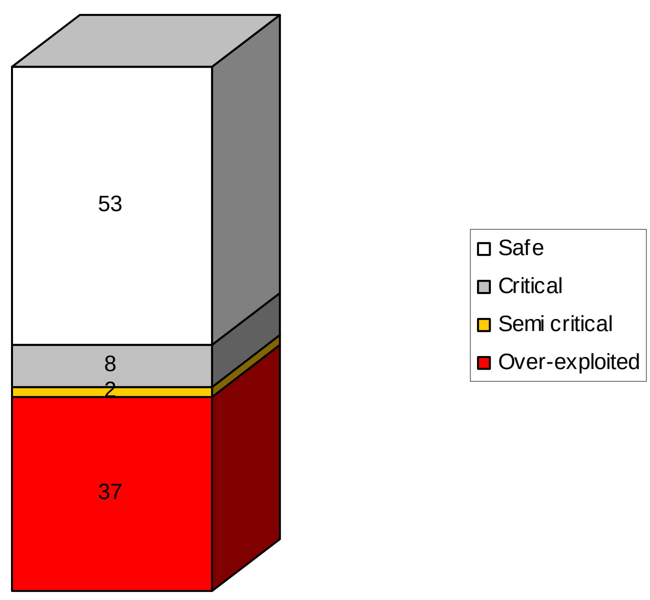
Table-3. Well density and area irrigated per well at Macro level in India

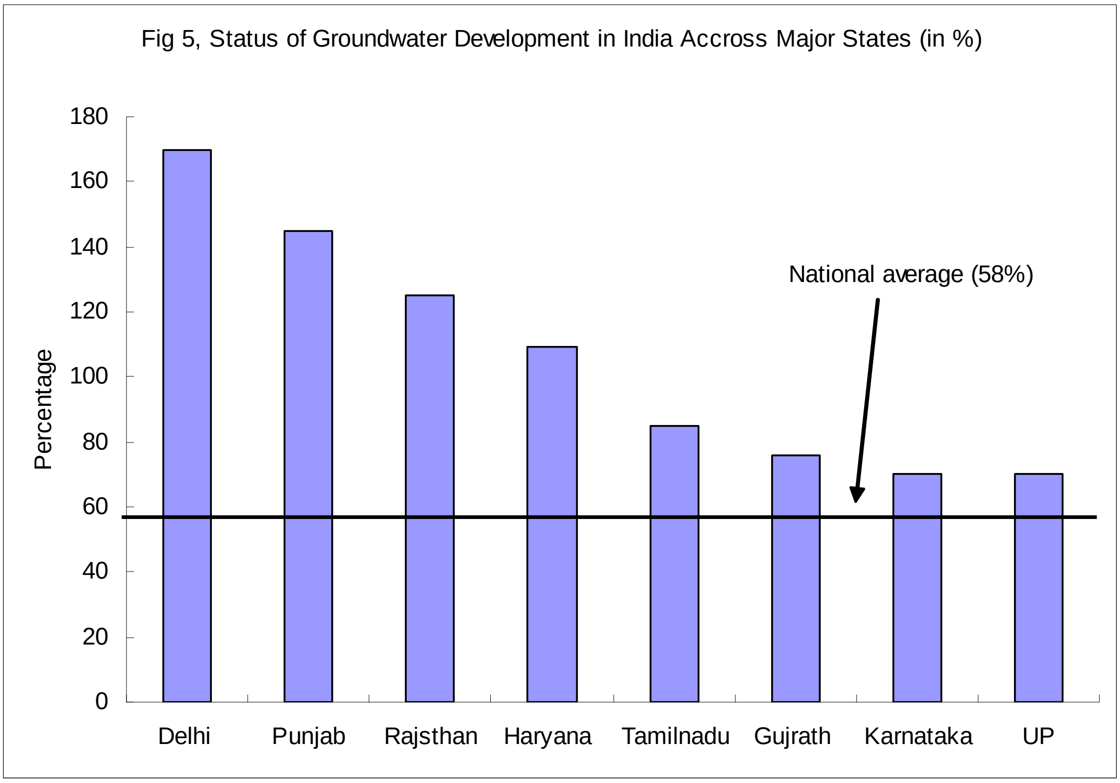
Year	Total number of wells (Million)	Well density (# of wells/100Ha of Net Sown Area	Well Irrigated Area (Million Ha)	Area Irrigated Per Well (Ha)
1950	3.8	2.3	6.7	1.76
1980	9.9	6.0	17.7	1.78
1990	14.2	8.0	24.4	1.71
2000	18.5	11.0	33.2	1.79
2007	25	15.0	35.0	1.4

As evident from the table-3, the total number of wells swelled almost six times since five decades. The well density has increased from just 2 wells to 15 wells per 100 Ha of net sown area leading to mutual well interference problems. Further, the area irrigated per well shows that in spite of increase in the number of wells over the years, the area irrigated per well has not been increasing and it remained almost 1.76 hectares and in recent years it has been drastically reduced. This clearly reflects that the groundwater development has crossed it limits and exhibiting scarcity.

Of the total number of wells, more than 60 % of the wells are concentrated in hardrock areas of peninsular India, where groundwater overdraft is a perennial problem due to lopsided extraction in relation to recharge. Groundwater is abundant in the unconsolidated rock formation mainly occupied by Gangetic basin. Nearly two thirds of India's geographical area constitutes hardrock formation (consolidated) where the groundwater recharge capacities are extremely low ranging from 6-8 percent of the total precipitation. The whole of peninsular India and the states of Punjab, UP, Haryana and Bihar and West Bengal has hard-rock or unconsolidated formation (Moench, 1992).

Fig 4, Current Status of Groundwater development in India (in %)





3) GROUNDWATER OVER EXPLOITATION: MAGNITUDE, CAUSES AND CONSEQUENCES

The overall stage of groundwater development (the ratio of annual ground water draft to the net annual groundwater availability) in the country is around 58 % (Figure 5-5). Though this figure implies a comfortable situation at the aggregate level, this does not reflect the lopsided degree of exploitation across different states. The degree of groundwater exploitation at macro level is highly skewed as is clear from the table 3. The stage of groundwater development in the country has doubled from 30 % to 58 % between 1990 and 2007 indicating the overexploitation of the aquifers. Even in recent years, the rate of exploitation is significant as reflected in the stage of groundwater development from 42 % to 58 % between 2000 and 2006. Further, in most of the peninsular, and western and northern states there has been steep increase in the number of critical and over-exploited blocks (table-4) reflecting over exploitation. According to the latest estimate, out of 5723 blocks, 1615 are semi-critical, critical or over-exploited (29%), as against 901 (14 %) during 2000 reflecting the disturbing trends in the groundwater exploitation. Of the total 839 over exploited blocks, 431 are from peninsular India comprising Karnataka, Andhra Pradesh, Tamil Nadu and Kerala (Map-1). In Karnataka alone, out of 175 taluks, 65 are completely over-exploited, while 17 fall under critical and semi critical category. Similarly in

Andra Pradesh, though the overall stage of groundwater development is below the national average, the number of over exploited, critical and semicritical blocks increased significantly as evident from the table-4. In Tamil Nnadu, also similar trend is evident. It is surprising to note that a state like Kerala, which receives highest rainfall in the country, is experiencing groundwater scarcity, as reflected in terms of increase in the number of over exploited critical and semi critical blocks.

Table-4. Groundwater Development across major states of India

State	# of blocks/ Talukas	Net Annual groundwater available (BCM)	Anuual ground water draft	Stage of ground water development	Over exploited	Critical	Semicritical
Andra	1104	32.95	14.90	45	219	77	175
Bihar	589	27.42	10.77	39	-	-	-
Gujarath	184	15.02	11.49	76	31	12	69
Haryana	108	8.63	9.45	109	55	11	5
Karnataka	175	15.3	10.71	70	65	3	14
Kerala	154	6.23	2.92	47	5	15	30
MP	459	35.33	17.12	48	24	5	19
Maharastra	231	31.21	15.09	48	7	1	23
Orissa	314	21.01	3.85	18	-	--	-
Punjab	138	21.44	31.66	145	103	5	4
Rajasthan	236	10.38	12.99	125	140	50	14
Tamilnadu	384	20.76	17.65	85	142	33	57
Uttarakanda	78	2.10	1.39	66	2	0	3
UP		70.18	48.78	70	37	13	86
WB	341	27.46	11.65	42	0	1	37
Total states	5705	398	230	58	837	226	546

Source: Central Groundwater Board, 2006

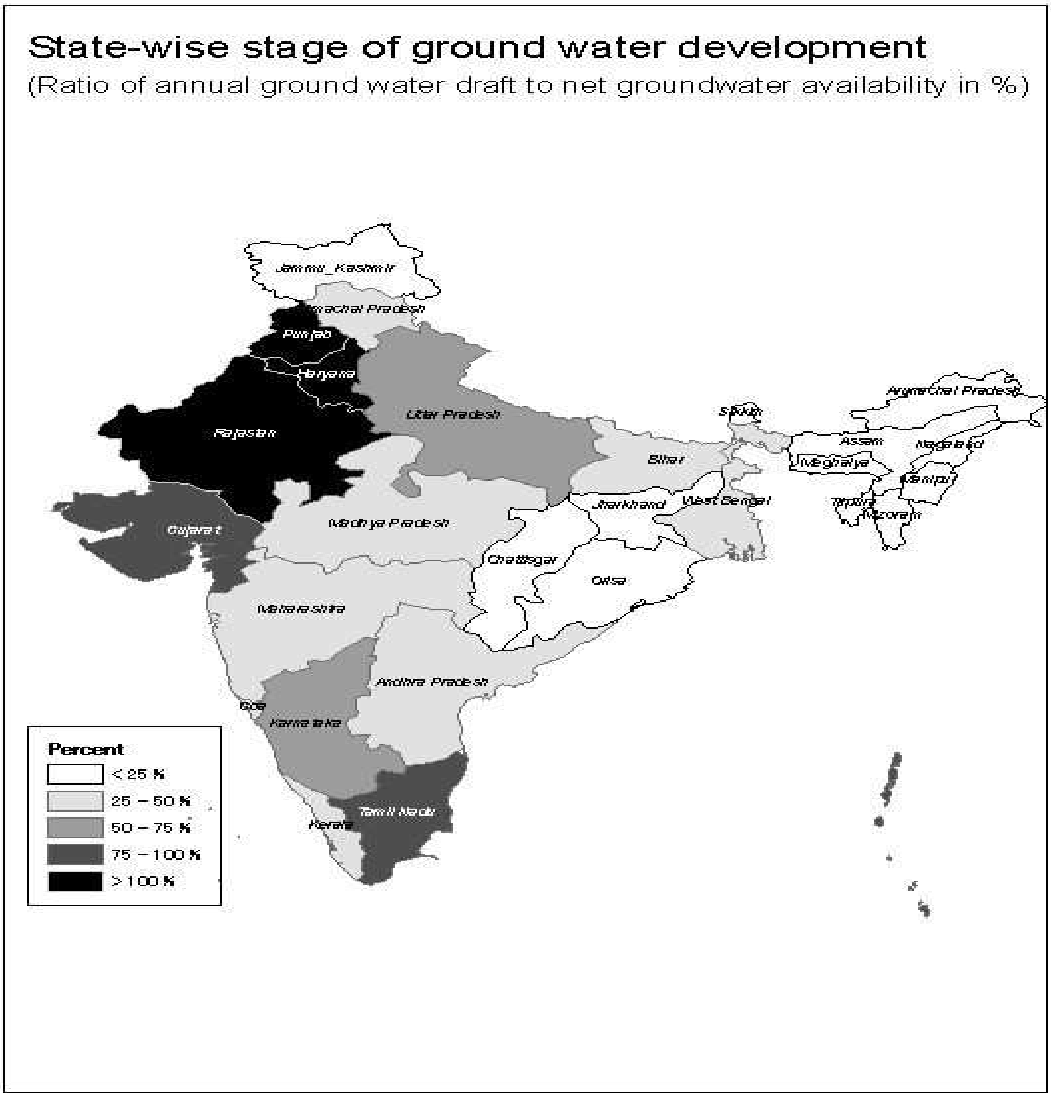
Table-5. Trends in the exploitation of groundwater in India between 2000 and 2007

Year	# of Assessment units Taluks//blocks/Mandals/ in the country	# of over exploited	# of critical blocks	Semi critical	Stage of groundwater development (%)	States comes under over exploitation/critical/semi critical/above average stage of groundwater development

2006	5723 (100)	839 (15)	226 (4)	550 (10)	58	Punjab, Rajasthan, Harayana, Pondicheri, Tamilnadu, Gujarath, Karnataka, UP, Uttarchal
2000	6106 (100)	516 (8)	385 (6)	-	41.5	Harayana, Punjab, Rajasthan, Tamilnadu, Gujarath, UP and Bihar

Figures in the parenthesis indicates percentage to the total

Source: Central Groundwater Board 2006



Thus, this is a cause of concern especially in the Peninsular hard rock areas, where a major part of the terrain falls within drought-prone zones. In addition to this, the number of borewells in semiarid area have been mushrooming. Hence, the per capita availability of groundwater has been dipping. Currently, the states like Tamil Nadu, Karntaka, Gujarath, Punjab, Hrayana, Rajasthan and Uttar Pradesh are heavily rely on groundwater for irrigation and their level of groundwater exploitation is above the national average (Fig 6). The groundwater overexploitation has continued unabated in the above states, hence appropriate policy interventions are an imperative in these states for sustainable management of groundwater. Studies indicate that in several parts of India like north Gujarat, southern Rajasthan, Saurashtra, Coimbatore and Madurai districts of Tamil Nadu, Kolar district of Karnataka, parts of Andhra Pradesh, Punjab, Haryana and Uttar Pradesh groundwater table has been declining at 1-2 m per year (Singh and Singh, 2002). Groundwater extraction and use has been spiralling in many areas beyond sustainable limits, especially in peninsular and western India. Scott and Shah (2004) report that in Karnataka around 20 percent of the total 1.2 million wells in the state were non-functional every year. The degradation of the groundwater resource base through over-extraction and pollution has increased rural poverty, social inequity and conflict in many parts of India, particularly in Tamil Nadu (Janakarajan and Moench 2006).Thus with the rapid expansion in groundwater extraction, the number of over exploited, critical and semi-critical blocks in the country registered an upward trend posing a serious threat to the groundwater availability and sustainability for the future use.

a) The Well trajectory and waves of change at micro-level

In order to understand the threats due to lack of appropriate policies for sustainable management of groundwater, the dynamics of groundwater development at micro-level need to be contextualized. In this regard, the micro-level changes are explained below:

With the onset of the green revolution, the demand for groundwater triggered enormously leading to agrarian boom. In most of the groundwater exploited states in India the rise and fall of groundwater economies witnessed four waves of change. The salient features of these waves of change are explained below taking an example from the typical hard rock belt of Karnataka state. The morphological changes in groundwater structures and other details are provided in the table 5.

Wave 1: In the first wave, the dug-wells continued to be the dominant means of groundwater exploitation until the mid 60's. Though traditional dug-wells existed during the 1950s, their number and spread were limited, and the water lifting devices were labor intensive. There was an effective conjunctive management of water between tank and well irrigation. Most of the wells were located in the proximity of tank commands enabling groundwater recharge and the cropping pattern was dominated by cereals demanding less water. This phase was very sustainable as the extraction rate was in limits with the natural rate of recharge. The Government intervention was confined towards providing credit subsidy to drill wells and buy pumpsets for lifting water.

Wave 2*:* During the 1960s, dug-well irrigation emerged due to fillip given to the rural electrification program of the Rural Electrification Corporation. The life of these wells was around 15 years till the 1970's (Table 5)**.** With the rapid expansion of commercialized agriculture, the traditional open-wells ability to support the increased demand for groundwater virtually shrunk. Hence, in order to enhance the yield of the wells, in the second wave, during the early 1970’s one or more bore(s) were drilled inside dug wells called dug-cum-borewells. The inbores had depth ranging from 150 ft to 250 ft.

Table 5: Morphological changes in groundwater structures in a predominantly bore well dominated area in Kolar District of Karnataka State, Peninsular India

Year of drilling	Type of well	Depth Range (mean) of well (feet)	Type of pump and Range of HP	Average productive age of irrigation wells	Range of investment per well (Rs in 000) (Mean)	Water yield of wells (gallons/hr)
1960-70	Dug well	25 to 40 (30)	Centrifugal 3-4	15	15 – 20 (17.00)	300-400
1970-1980	Dug-cum bore-well	150-250 (192)	Centrifugal 5-6	13.1	25-50 (32.10)	1500-2000
1981-1990	Shallow bore-well	200-250 (232)	Submersible 5-10	12.3	50-75 (67.40)	2000-5000
1991-2000	Surface bore well	250-500 (312)	Submersible 5 -7.5	10.3	75-100 (89.61)	5000-2500
2001-2005	Deeper bore-well	500-700	Submersible 7.5-10	6.1	100-120 (112.14)	2500-2000
2005-07	Deeper bore-well	700-1000 (658)	Submersible 10-15	3.1	120-150 (127.35)	2000-1000

Investment per well includes all costs of irrigation well including irrigation pump set

This phase was coincided with the introduction of green revolution technologies. There was the rational and efficient use of water, as farmers were paying electricity charges based on metered value. In this period, the traditional water lifting devices declined drastically with the access to extraction technology. There has been boom in the groundwater based agriculture with substantial increase in income and employment. Government intervention continued to provide subsidized institutional credit for well drilling and purchasing water lifting devices. In addition electricity subsidy on flat rate was also introduced during this phase.

***Wave 3*:** The dug-cum-bore-wells were the dominant structures till the 1980’s. Due to proliferation of bore-wells across all directions, shallow wells became defunct, indicating early symptoms of groundwater over exploitation. Consequent to failure of dug-cum bore-wells, farmers ventured drilling surface bore-wells with a depth ranging from 200 to 400 ft since 1990s in the third wave. Thus, bore well intensity increased with drop in water tables as well as drying up of shallow bore-wells. With diversification of agriculture towards high value crops, investments on groundwater exploration and extraction further triggered. The rate of returns to the investment on groundwater was manifold (Nagaraj, 1995). Thus, this wave manifested secular decline of groundwater water table. There has been increase in the real cost of pumping groundwater implying economic scarcity of groundwater. Groundwater based economy continued to boom but tensions between economy and ecology (Shaw 2002). Populist measures of Government Subsidy programme continued with weak groundwater regulations.

***Wave 4*:** From the early 1990’s, with further improvement in technology of exploration and extraction, surface bore-wells (with a diameter of 6 ft and a depth of more than 400 ft with submersible pumps of 5 to 10 Horse Power) have become popular due to the advent of exploration of rig technology implying the fourth wave of change. In the fourth wave, the depth of bore-wells increased beyond 900 ft with access to supra-technology. Thus, groundwater extraction exceeded the threshold limits of maximum sustainability yield leading to groundwater drought. The groundwater based bubble bursts with deep groundwater crisis. In the process the small and marginal farmers were worst hit.

Kolar District in Karnataka state is a classic case of intensive groundwater development witnessing a boom and a turning point of bust. The study conducted in this district indicated that the depth of the bore wells increased 200 ft to 1220 ft between 1971 to 2008 as evident from the Fig-7 (Nagaraj et al 2009). This trend is common across dry districts of the state. The investment on wells is further triggered by uncertainty in rainfall. The mode of extraction of groundwater during 1970s and 80s in all the systems was from the ordinary 3-4 HP pumpset, later in the 1980s, these were replaced by submersible pumpsets to extract water from the deeper layer of the aquifer. Thus groundwater based agriculture prospered with groundwater boom and reached a turning point leading to burst. The implication is that in hard rock areas of peninsular India, groundwater depletion is unabated and the effects have been disastrous. Many farmers are resorting to dryland agriculture due to widespread failure of borewells and extreme scarcity of groundwater. This has become a threat to livelihood security of large number of farmers who are depending on directly or indirectly on this valuable resource. Now, the challenge is to introduce the corrective measures focusing on resource management rather than resource development.

b) Factors responsible for over exploitation

Ever since the onset of green revolution in India, the landscape of agriculture has drastically changed especially with groundwater irrigation. Since groundwater access enabled to take multiple crops, the demand for ground water has drastically triggered. Most of the commercial crops grown under groundwater irrigation are highly water intensive. Since, farmers have invested a sizable amount of capital on borewells, their drive has been to recover investments soon by growing cash crops. In addition, the populistic policies of the Government like subsidized credit, electricity, support price for crops like rice, wheat and sugarcane, rapid strides in well exploration and extraction technology, invisible and open access nature of groundwater resource, demographic shifts, lucrative markets for commercial agricultural products and week groundwater regulations strongly influenced the groundwater development and use in the country in general and the peninsular states in particular. Further, inadequate efforts towards groundwater recharge, conservation and the efficient use of water are also contributed to the crisis. Since, the electricity charges for pumping groundwater for agricultural use is based on flat tariff and it is highly subsidized, the marginal extraction cost is virtually zero. This inevitably led to over extraction of groundwater not matching the rate of recharge leading to groundwater depletion and plummeting water table in many parts of the country. The groundwater over mining (sustained withdrawal beyond the aquifer’s safe yield) has resulted in severe undesirable environmental economic and equity problems creating disturbing trends in the farm sector.

c) Consequences/implications of Over-Exploitation

In hard rock areas, the investment on well irrigation is increasingly becoming a risky venture as the well failure rate is increasing over time. Farmers have lost their precious lumpy capital investments not only on dug-wells, dug-cum-bore-wells but also on bore-wells due to high well failure probablity and lack of recharge efforts. The productive life of wells has fallen from around 15 to 3 years, with well depths increasing astronomically from 200 to 1200 ft. The real cost of pumping is increasing steeply with increased pumping energy. Due to increased well density over time and space and non-adhering of the spacing limits between wells, cumulative well interference problems have increased. The yield of the water in bore-wells has been dwindling and the quantity discharged is inadequate to irrigate the crops using conventional methods of irrigation. Hence, the area irrigated per well is shrinking.

In response to groundwater scarcity, the farmers are coping through drilling new wells, deepening existing wells, adoption of drip irrigation system, investment on improved storage structures, conveyance, shifting cop pattern, buying water. The cost of coping mechanisms is swelling due to negative externalities of groundwater depletion. Studies indicated that there has been rise in the cost of groundwater extraction from Rs. 51 to Rs. 82 on to Rs. 264 per acre-inch reflecting scarcity of groundwater between 1980’s to1990’s and 2000 respectively (Nagaraj and Chandrashekar 2003, Chandrakanth and Rome 1990). Thus, there have been manifestations of both physical and economic scarcity of groundwater.

Due to failure of wells many farmers have been shifting over to dry land agriculture and even some of the farmer’s suicides were partly attributed to well failures. In the process of over exploitation, the small and marginal farmers have been the worst hit, as their ability to invest on deeper wells is constrained. Unscrupulous human induced interventions in groundwater extraction affected the ecological and environmental balance. Many wetlands and traditional perennial streams disappeared due to innumerable wells sucking water from them. The spots of desertification of agricultural are evident, which were green earlier. There has been widespread scarcity of drinking water for both humans and livestock, affecting gender as women manage the water supplies in domestic use. In addition to quantity depletion, the quality of groundwater is also deteriorating in many parts of the country due to pollution of aquifers and increased depth (Reddy 2006). The implication is that the groundwater resource is becoming an endangered resource over time affecting not only the present generation, but also the future generation.

4) POLICY APPROACH:

The water policy should provide the overall framework for efficient, equitable and sustainable management of available water resources across different sectors and regions of India. This needs both short and long term strategies with periodic review of water policies and laws in response to the economic and technical dynamics of groundwater situation. The policy should serve as a blue print and guide for action. It is necessary to ensure that all the relevant stakeholders are properly represented in the planning process from village to the district level, so as to reflect the local realities for viable solutions.

Critical Management Gaps

Surface irrigation projects in India are planned and executed by Government for the benefit of the society. Many of them are multipurpose river valley projects. In the recent years, due to riparian rights, many states are involved in resolving their dispute resolution in sharing river waters. Groundwater extracted from borwells is an invisible resource and in the hard rock aquifers which occupy 60 percent of India's geographical area, there is technical difficulty in delineating aquifer boundaries and hence there is a problem in monitoring and regulation. In addition with such a large number of farmers (20 million irrigation pumpsets) across wide area, the governance is challenging with high treansaction costs due to following factors:

1) Lack of precise information system on volume of groundwater availability, quality, extraction, recharge and overdraft at the micro-level for the user and for the planner.
2) Well inventory along with the profile of groundwater users is vital for the implementation of any groundwater management strategy, but seldom available.
3) Inadequate technical support services and resource persons well versed with hydrogeology and understanding groundwater dynamics over timescale at the user level. The technical inputs and advice to the users is indispensable for sustainable development
4) Lack of well defined groundwater use rights constrained to regulate groundwater extraction.
5) Weak planning and institutional framework to guide development of the resource at different levels. As a result, investments on groundwater have continued unabated leading to overdraft.
6) Further, there is a severe competition for groundwater use across different uses, but with no mechanism to allocate the resource among different sectors on the lines of IWRM
7) There is total illiteracy regarding all aspects of groundwater in stakeholders who fail to appreciate the need for sustainable use
8) There are no appropriate institutions addressing groundwater extraction, quality concerning quality pumps, depth, pollution of aquifers. Thus, such critical management gaps need to be addressed on priority basis to correct groundwater distortions /externalities to treat the sustainable path of extraction. There is policy failure to address these critical challenges in managing groundwater due to the common pool nature.

The existing Institutional arrangement

The exponential growth in ground water extraction is a matter of concern. Groundwater aquifers are seldom monitored and the resource availability is not properly estimated. Intensive groundwater development is not accompanied by appropriate institutional interventions and investments towards governance and management (Kemper, 2007). At present, well drilling is treated independently of resource availability and institutions as there are no licenses or permits needed to drill, and no spacing or depth regulations, when farmers are making their own investment, without any support from institutional finance. Groundwater extraction has followed in close lines of what Ciriacy-Wantrup (1968) describes as the 'fastest' with the 'mostest'. ignoring the equity and environmental implications.

Legal framework

In India groundwater extraction is implicitly governed by the Indian Easement Act of 1872. If groundwater extraction is strictly adhered according to the Act, cumulative interference externalities can be reduced to a large extent. However due to the sheer numbers of pumpers (around 20 million, the largest in the world) of groundwater pumpers for irrigation, the transaction costs of implementation are colossal. Thus, at present there are no institutions pertaining to issue of permits, number of wells to be drilled and the volume of water to be extracted. When the constitution of India was promulgated in 1949, groundwater irrigation was not prominent and it was in infant stage. The problems of groundwater overdraft were not anticipated and hence the institutional framework did not draw specific attention. In the absence of specific provisions governing groundwater extraction, this implies 'asymmetry' between groundwater and surface water, since use rights are considered in groundwater than in surface water (Foster, 2004). The 1st National Water Policy was approved by a ministerial group in 1987. With respect to groundwater, the policy indicted that extraction should not exceed recharge and conjunctive use of surface and groundwater should be practiced. But, this is yet to take off despite the new water policy developed in 2002.

Property rights structure

Groundwater is attached like a chattel to land, without limits on extraction. Thus, only the landowner can own groundwater right implying that landless does not have any stake in the resource. This reflects inequity in access to groundwater resource. The existing property rights to groundwater in India (Singh, 1993) is ambiguous. For instance, wells and borewells (pvt) cannot have different rights. It is also mentioned that for borewells (private) the State has no right to own/regulate. If this is true for borewells, it is true for open wells also. In fact at best, it is the Indian Easement Act, which at least has addressed *de jure* the groundwater rights. The recent report of the national planning commission also addresses in detail on the nature of rights on groundwater in India
http://planningcommission.nic.in/reports/genrep/rep_grndwat.pdf)

Groundwater Bill

The Ministry of Water Resources of the Government of India proposed the Groundwater (Control and Regulation) Bill in 1970 and revalidated it in 1992 to regulate and control the development of groundwater. This was circulated to all the states with an advice to enact with necessary modifications since water is a state subject. The bill enables state governments to establish a groundwater authority and appoint its chairman and members. The authority can notify the specific areas of overdraft to regulate over-extraction in the interest of the public. The model bill (*groundwater control and regulation Bill, 1992*) is not yet approved by many state Governments. The Bill is under severe criticism, as there is no representation from user groups. The Model Bill reflects a kind of command-and-control mechanisms which often fail to work under common property regime.

The only regulatory mechanism to check overexploitation is the restriction of finance through NABARD in overexploited areas and enforcing spacing norms. In the case of non-institutional financed wells, there is no mechanism to control overexploitation. Since water is a state subject, the groundwater laws are to be enacted by states. So far 11 States/ UTs viz., Andhra Pradesh, Goa, Tamil Nadu, Kerala, West Bengal, Bihar, Himachal Pradesh and Union Territories of Chandigarh, Lakshadweep, Pondicherry, Dadra and Nagar Haveli have enacted and implemented groundwater legislation. However, the effectiveness of their implementation and enforcement is not known (Malick 2008). There was an inordinate delay in the implementation of model groundwater bill due to political reasons. Unless the Groundwater Act is implemented in its true sense, it is likely that the groundwater crisis aggravates and the farmers, especially small and marginal farmers would suffer the most.

The institutional measures both formal and informal devised at the central or state in terms of use rights, well permits to extract groundwater, groundwater tariffs, and subsidies should be supported by legal and regulatory framework in order to allocate, administer and enforce them. This has worked in some developed countries, where number of users is manageable, but in India, this is not effective due to the largest number of users (in the world) so widely spread across the nation. Moreover, the institutional and regulatory framework is very weak in India as explained. However, there are other indirect levers that could aid in groundwater management. These include energy pricing, support prices for the products using groundwater and technological measures.

Groundwater Management approaches:

Currently, the existing groundwater laws are unenforceable and pricing of electricity or water is not plausible due to socio-political and economic intricacies . Moreover, transaction cost of implementation of regulatory and economic instruments is colossal considering the size and spread of well owners. Thus, designing and developing of appropriate groundwater management systems is a real challenge in India. Nevertheless, considering the seriousness of groundwater overdraft, the issues of groundwater management and its governance are in forefront. In this regard, a host of direct and indirect demand management and supply augmentation approaches are vital in addressing groundwater issues, discussed below.

CONTROLLING GROUNDWATER DEMAND THROUGH TECHNOLOGICAL IMPROVEMENTS

The market based and institutional approaches for addressing groundwater extraction are crucial though it is a serious political economy question and needs to be addressed on watershed level. Independent of such a policy, individual farmers have technological options to use water more efficiently than their present level. Further, the use of appropriate technologies can bring down the demand for groundwater. These measures could act as indirect demand management technological tool to regulate groundwater use. They include *inter alia*, cultivation of drought resistant less water intensive varieties, aerobic rice, system of rice intensification, zero-tillage, alternate wet-and-dry irrigation and mulching. These technologies deserve to be subsidized for their widespread promotion.

Increased efficiency in water use leads to saving in water and curtails the demand for groundwater. In order to improve the irrigation efficiency by the farmers, investments in better technology is crucial. In this regard, subsidies play an important role in promoting such technologies. These include investment on piped irrigation instead of open channel irrigation, drip and sprinklers irrigation, soil leveling, mulching. The adoption of Drip irrigation has several advantages such as (i) lower groundwater extraction, (ii) lower electricity use for pumping groundwater, (iii) coping with low yielding groundwater well/s, (iv) extending the age of existing wells and, (v) contributing towards sustainable use of groundwater. Thus tying institutional regimes with technological solutions will result in a win win situation for farmers.

Improving efficiency

Currently irrigation pumps are working at abysmally low efficiency due to the use of inefficient lifting devices like imported low quality pumps, aircompessors and piston pumps (Kurien and Sinha, 2007). This leads to over-exploitation of the aquifer and also disturbs their hydraulic efficiency. The main reason for using the low quality substandard pumps is that electricity is free for agricultural pumpsets. Hence, there is no incentive (disincentive) for farmers to conserve (overuse) energy. If pump efficiency is improved by10 per cent over the existing level of 45 %, substantial electricity could be saved. In this regard, strict law should be enforced to replace all the existing pumps and rectification scheme may be introduced through NABARD assistance. Thus investment on high quality efficient pumps is desirable given the precarious position of energy position in the country.

***Economic Incentives**:*

One of the innovative approaches to deal with over exploitation problem is to extend a package of economic incentives to the users to cut down the extraction rate especially during dry (summer)-season. This could be done by best groundwater irrigation management practices such as use of high quality efficient pumps for lifting water, adoption of water-saving technologies such as drip and sprinkler irrigation, concrete lining of piped water distribution channels or piped distribution networks irrigation, water-saving technology, shift in crop pattern in favor of less water -intensive crops and modern agronomic practices. In this regard, appropriate financial and logistical support as well as market support for the product produced using groundwater is crucial. In addition, quality power supply to operate pumps during day time for a fixed period is equally important.

Need for cooperative action on community basis:

Another plausible way of regulating the groundwater exploitation is through “User Groups” on community basis. In many states where watershed development projects have been implemented, the Watershed Sangha’s have been established with the support of NGO’s. These village level institutions can be better utilized for implementing action plans with respect to groundwater conservation and recharge activities. The enforcement for regulation /reduction / restriction in groundwater usage should be made effective by state governments through users group on community basis with the involvement of Panchayats. A set of minimum rules needs to be designed with all the stakeholders, as groundwater is a common property resource. The user groups should be empowered in regulating groundwater usage through minimum agreed rules. The farmer should be responsible not only for discharge (pumping out groundwater) but also for investing on recharge pit to recharge his /her borewell(s), investing on farm pond to serve as recharge, investing on drip irrigation, using the right sized pump, right horse power and right quality. In addition, public investments on rain water harvesting on watershed basis, tank rehabilitation and percolation tanks should continue in high well intensity areas. Thus, if the community adopts a participatory demand and supply management approach, it is possible to attain the long term sustainability in groundwater by curtailing demand for groundwater and enhancing conservation.

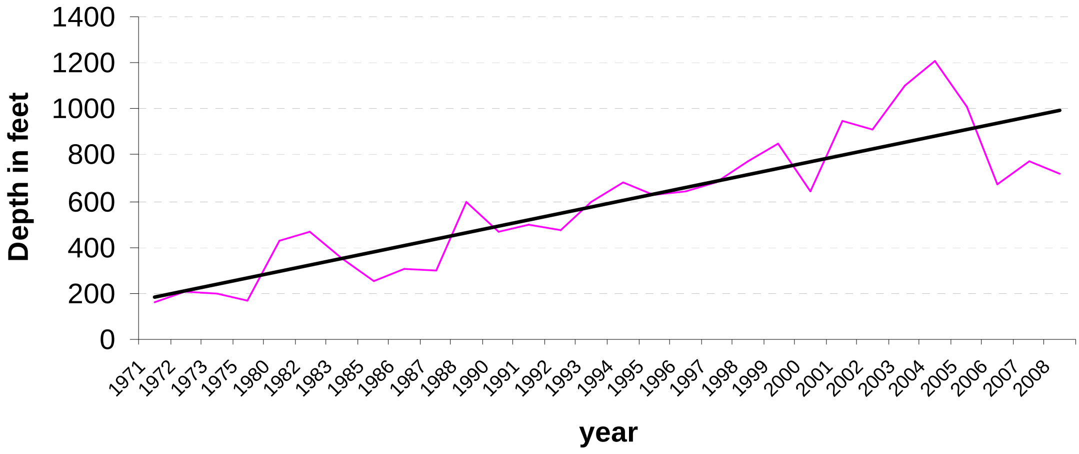
Energy-irrigation nexus:

Since direct management of groundwater through regulatory measures is at a significant transaction cost, indirect measures such as managing electricity supply and pricing could be alternative options for indirect management of both groundwater and energy use (Shaw, 2007). Lack of appropriate energy policies for groundwater irrigation not only contributed to overexploitation but also discouraged the conservation of both energy and groundwater. Since marginal cost of pumping is zero due to policy of no tariff / flat tariff, the extraction continues unabated. The supply of uninterrupted quality power for irrigation is the bottleneck for farmers. In addition, farmers are adjusting with power supply during the evening and night hours by installing automatic starters, filling the failed open wells with water whenever the power is on, and repumping from the open wells later. This results in wastage of power and groundwater, as there is no control over both during the dark hours. Even to this day, unscheduled power cuts in rural areas are rampant. According to the Central Electricity Authority, agriculture pumpsets use 29 % of the total electricity in India. However, in most of the groundwater intensive use states, the average electricity use per irrigation pumpset exceeded the national average. It is heartening to note that at present according to NSSO (2005), 66 percent of the power is from diesel and 34 percent is from electricity for drawing groundwater in India.

Since electricity is subsidized, poor financial position of the power utilities has led to under investments in power generation and power distribution system improvements. Irregular supply of power leads farmers to pump whenever power is available rather than when crops need water. This leads to inefficient and wasteful use, over extraction of groundwater and lowered water table contributing for overexploitation. Lowered water tables force farmers to use high capacity pumps to lift water from deeper aquifers. According to IWMI, sustaining a prosperous groundwater economy with a viable power sector is feasible, but this requires that decision makers in the two sectors jointly explore energy-groundwater co-management. They advocate a flat tariff accompanied by better management of high quality but carefully rationed power supply to maintain the fiscal sustainability of energy sector and environmental sustainability of groundwater irrigation. In this regard, state governments can draw lessons from Gujarat’s model of Jyotirgram

Yojana, where farmers are offered rationed power supply reducing inefficiencies in power and groundwater use.

Fig. Pattern of Depth of Bore-wells in the Kolar District of Karnataka, Peninsular India:



Supply side interventions:

Thus far, policy response to groundwater overdraft in India has been through investments on watershed development programs, minor irrigation programs and other groundwater recharge activities. With watershed development programs, there has been a discernible positive impact on groundwater recharge in parts of peninsular India (Nagaraj, et al. 2008, Seema et al. 2008, Palinisami and Kumar 2005). As a prima facie indicator, depth of bore-wells reduced from 1200 ft to 600 ft between 2005 to 2008 due to groundwater recharge on account of watershed development in Kolar district of the Karnataka state (Fig-1).

Thus, the positive externalities generated are associated with the investments on replenishment interventions such as construction of water harvesting structures through watershed development, desilting of existing tanks and artificial recharge projects in overexploited area. It was estimated that the recharging capacity of a normal percolation tank is about 7.87 mm/day, while a de-silted percolation tank can recharge up to 20.40 mm/day (Patel, 2002), and the radius of this impact ranges from 1.1 km to 0.72 km, depending on the type of soil. Of late, in many states like Karnataka, Maharastra and Andrapradesh public investment on water harvesting structures like recharge pits and farm ponds for improving groundwater recharge has been gradually improving. Similarly in Karnataka and other states,some irrigation tanks have been converted into percolation tanks for groundwater recharge in groundwater depleted area. Though this has created tangible positive impact in terms of supply augmentation of groundwater, unfortunately little attention is focused on the economic use. According to the expert committee of the planning commission, artificial recharge can only delay the crisis but cannot prevent. In spite of supply augmentation, water table is rapidly falling and pumping costs are increasing. Anything free, people would misuse. Once we recharge groundwater and price electricity, water use would reach economically efficient levels.

International experiences

In most countries overextraction of groundwater and quality degradation are becoming major issues. These problems are being addressed by a combination of market and institutional approaches. In France, there has been success in dealing with groundwater overexploitation in the Beauce area through the involvement of user groups in the Basin Committee. In addition, regulatory measures, economic instruments, dissemination of vital technical information to users for efficient use of the resource and incentives for conservation measures are also being implemented. The economic levers include appropriate pricing of water and rationing the resource in terms of fixing quotas and extending incentives and subsidies. The regulatory approaches include issuing permits for extraction, producing feasibility report in the case of fresh wells monitoring and enforcing, imposing penalties and sanctions on offenders, and putting restrictions on wasteful use of water and overdraft. There are three levels of rules evolved by the Basin Committee for managing the groundwater basins in the event of drastic fall in the water table. The SI, S2 and S3 are the threshold levels of the water table referring to altitude above the MSL in meters. When groundwater table dips to the SI threshold, the irrigators are alerted to use the water more economically and to adopt the conservation measures. Similarly, irrigation is prohibited two days in a week for cereals and one day for other crops when water table drops to S2 level. In the case of S3 there is a dis-equilibrum between the users and the committee and action is needed (Nagaraj 1998)

States and local governments have traditionally managed groundwater in the western United States. In some states the management systems have been established by state governments and regulated at the state level. In some other states the management has been delegated to local institutions such as a water management or Natural Resource Districts (Smith 1993). In the western US the groundwater overdraft problems are being effectively addressed through institutional policy instruments with local control. (Moench,1992). The Nebraska State in the US is the frontrunner to initiate a variety of controls with local efforts to manage the groundwater overdraft. These measures include formation of natural resource districts with varying responsibilities over groundwater issues, creation of an enabling framework specifying user rights, correlative rights to a reasonable use, issue of permits for extraction, allocating quotas and even declaration of moratorium on new wells in critical/over exploited areas. These regulations enabled to set an upper threshold for extraction of groundwater and made groundwater legally scarce. This has had a profound impact on use pattern and conservation of groundwater in the region (Nagaraj et al. 2000).

China has been proactive in addressing groundwater over exploitation through regulatory measures compared to many south Asian countries, although its performance is not satisfactory. It has implemented a blend of measures ranging from well permits, withdrawal permits, differential and penal pricing, direct regulations and sealing of wells, creating alternative water supplies and promoting water saving technologies. This strategy has been relatively successful with industry than agriculture (Shaw et al 2006). China with stronger state commitment to groundwater regulation, with a more elaborate reach and local authority structures is still facing a herculean task to regulate groundwater overdraft (Malik, R.P.S. 2008).

In Mexico, establishment of Aquifer Management Councils (COTAS) is promoting awareness and water saving investments (Kemper, 2007). Barring Philippines, in most South East Asian countries, groundwater depletion is not a felt problem. However, there has been poor performance of irrigation sector due to suboptimal utilization , low water productivity; suitability and cost-effectiveness of current irrigation technology, sustainability and subsidy, adequacy of irrigated agriculture support services and functions, weak R&D and extension services, inadequate institutional arrangements and mechanisms, and the roles of the different stakeholders in irrigation development (David 2004). In Japan, water is well focused on water works management and not on water use management.

Thus, international experience shows that a combination of approaches ranging from regulatory to institutional and economic instruments could be deployed to deal with emerging problems of groundwater overdraft. Groundwater management approaches effective in one country may not be effective in another country due to variation in type of aquifers, number of users involved, alternative sources of water and the larger political economy.

SUMMARY AND CONCLUDING COMMENTS

With 40 percent of the cultivated area being irrigated and 70 percent of the irrigated area devoted to food crops, irrigation makes India's farmers to be food and livelihood secure with certainty, meeting needs of population. Over time, surface irrigation has been stagnating and dispersed groundwater irrigation has been exponentially growing. Within the decade of 1998-2009, groundwater extraction jumped from 38 percent to 58 percent. Soft policies of the successive governments concerning electricity, credit, debt waivers, support prices on the one hand and complementing technological innovations in well exploration, extraction and use on the other in a weak groundwater institutional framework have been contributing to overextraction of groundwater in a political economy situation. Since the last four decades, groundwater extraction exhibited a trajectory of initial utilization, agrarian boom, growing scarcity and eventually bust with rapid fall in groundwater table in semi-arid regions in the hard-rock aquifers. This has forced several marginal and small farmers to shift to dryland agriculture as they could not bear the brunt of premature / initial failure of wells increasing economic scarcity of the precious groundwater resource for irrigation.

The weak and ineffective institutional efforts of the governance to contain groundwater overdraft have contributed to the predicament. The challenge is thus to frame effective institutions balancing resource management with resource development. As water is indispensable for agriculture and domestic purposes, innovative institutions, technologies of micro-irrigation, rainwater harvesting, provision of irrigation management services, and market measures subsuming property rights, water entitlements, abstraction limits are crucial.

Thus far, supply side of groundwater is being addressed by the State through schemes such as watershed development, tank rehabilitation, while the demand side is inadequately dealt. Thus, key actions are necessary for demand and supply management on individual and community basis. Farmers should be educated regarding groundwater recharge on their farm in addition to recharge efforts at the community level. The community based approach to regulate groundwater incorporating IWRM is by promoting user groups with technical support and training involving local government, and the community.

Major policy changes on energy use and technical aspects for accurate assessment of groundwater recharge and extraction, maintenance of isolation distance as well as depth, cap on the number of functional irrigation wells per farm, quality pumpsets, information dissemination, implementation of the best practices and appropriate crop pattern are in order. Groundwater institutions and management approaches devised and effective in one situation / country may not be effective in another situation / country due to hydrogeological, agroclimatic, market, and political economy variants. Thus a strong S and T with equally strong R and D are crucial for developing technological innovations in extraction and use, resource management, markets and institutions. Initially, this requires, on a pilot scale, demonstration in a representative area the measures for replication in similar areas with mid term corrections.

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