India's Groundwater Challenge and the Way Forward

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The groundwater crisis is acquiring alarming proportions in many parts of the country. Strategies to respond to groundwater overuse and deteriorating water quality must be based on a new approach involving typologising the resource problems and redefining the institutional structure governing groundwater. This approach is based on the notion of groundwater as common property. The complex nature of groundwater problems in India implies that a detailed understanding of regimes in different hydrogeological settings and socio-economic situations is the prerequisite for sustainable and equitable management. Further, the management strategies should be specified keeping aquifer-scales in mind. For the adoption of this new approach, reforms are needed in how we assess groundwater resources, map aquifers, monitor quality and in the legal and institutional framework for groundwater governance. A national programme of groundwater management based on this process-specific approach is needed to address the challenge.

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Groundwater resources play a major role in ensuring livelihood security across the world, especially in economies that depend on agriculture. The socio-economic dependency on groundwater is explained over a range of factors by Burke and Moench (2000). They explain the intricacy in managing groundwater resources. At the same time, groundwater systems have become the "lender of last resort" and depletion of renewable groundwater stocks is taken as the first indicator of water scarcity (Shah and Indu 2004). Moreover, groundwater is considered to be less vulnerable than surface sources to climate fluctuations and can therefore help to stabilise agricultural populations and reduce the need for farmers to migrate when drought threatens agricultural livelihoods (Moench 2002). In other words, groundwater resources provide a reliable drought buffer in large regions of the world (Calow et al 1997).

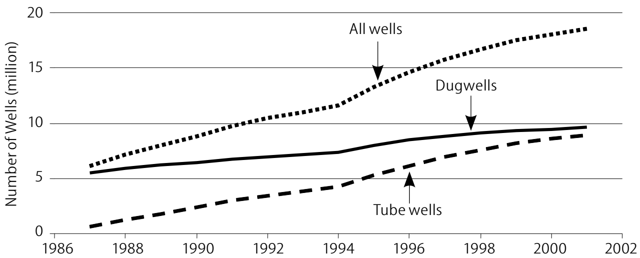
The ability to access groundwater plays a major role in reducing risk and increasing incomes (Moench 2003), especially when other modes of irrigation are absent. In this paper, we attempt to capture the multiple dimensions of a resource that is used on a large scale in most populated regions of the world, primarily due to such ability. We keep an India-focus for the reason that India has emerged as one of the largest users of groundwater in the world. Our own experience suggests that groundwater management in a country like India is proving to be a challenge on many counts. We attempt here to unpack myriad problems and responses associated with groundwater use and suggest a way forward to meet some of these challenges.

1 Groundwater in India

India is now the biggest user of groundwater for agriculture in the world (Shah 2009). Groundwater irrigation has been expanding at a very rapid pace in India since the 1970s. The data from the Minor Irrigation Census conducted in 2001 shows evidence of the growing numbers of groundwater irrigation structures (wells and tube wells) in the country. Their number stood at around 18.5 million in 2001, of which tube wells accounted for 50% (Figure 1, p 38). There is no reason to believe that the growth in the number of these structures have slowed down since then. In all likelihood, the number of groundwater irrigation structures is now around 27 million with every fourth rural household owning at least one such irrigation structure (Shah 2009).

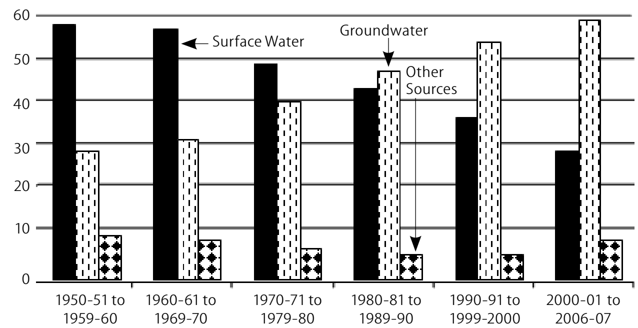
The share of groundwater in the net irrigated area has also been on the rise. Of the addition to net irrigated area of about 29.75 million hectares between 1970 and 2007, groundwater accounted for 24.02 million hectares (80%). On an average, between 2000/01 and 2006-07, about 61% of the irrigation in the country was sourced from groundwater. The share of surface water has declined from 60% in the 1950s to 30% in the first decade of the 21st century (Figure 2).

Figure 1: Growth of Groundwater Irrigation Structures (1986-2001)



Source: Minor Irrigation Census, 2001.

Figure 2: Decadewise Share of Surface Water and Groundwater in Net Irrigated Area (%)



Source: *Indian Agricultural Statistics (2008).*

The most dramatic change in the groundwater scenario in India is that the share of tube wells in irrigated areas rose from a mere 1% in 1960-61 to 40% in 2006-07. By now, tube wells have become the largest single source of irrigation water in India. Data from Minor Irrigation Census (2001) showed that three states (Punjab, Uttar Pradesh and Haryana) accounted for 57% of the tube wells in India. On an average, there were 27 tube wells per square kilometre of net sown area in Punjab, 21.5 in Uttar Pradesh and 14.1 in Haryana in 2001. Interestingly, 68% of the households owning tube wells were of small and marginal farmers, indicating the growing dependence of these households on tube wells as a source of livelihoods. With an estimated 27 million odd groundwater structures, India is fast hurtling towards what Shah (2009) rightly terms "groundwater anarchy". And this, despite the fact that India, along with China and the United States, has far outpaced the world in building large dams (World Commission on Dams 2000). As a stern warning, the report of the Expert Group on Groundwater Management and Government states that in 2004 some 28% of India's blocks (nationally recognised administrative units) were showing dangerously high levels of groundwater development[1] as compared to 4% in 1995 (Planning Commission 2007). A more recent assessment by NASA showed that during 2002 to 2008, three states (Punjab, Haryana and Rajasthan) together lost about 109 km^3 of water leading to a decline in water table to the extent of 0.33 metres per annum (Rodell et al 2009). The state-wise status of groundwater resources as on March 2004 is given in Table 1. We can see that in many states, the net draft of groundwater is either in excess of or close to the net available resource, implying that these states are facing a situation of dangerous overexploitation of their available groundwater resources.

2 Defining Groundwater Vulnerability: A District Level Picture

Though groundwater overuse was recognised as a serious problem for quite some time (Dhawan 1995; Moench 1992; Macdonald et al 1995), conventional approaches to groundwater in India until the mid-1990s have involved a clear focus on the "development" of groundwater resources. The mid-1990s saw a slow and reluctant change in thinking, from a development to a management mode. The new thinking, which attempted to look at managing groundwater beyond sinking dug wells and drilling tube wells or bore wells, began to be backed by data from state and central groundwater agencies. Simultaneously, the methodology of groundwater estimation was also improved (GEC 1984, 1997). We have district-level data sets on groundwater potential and use from the two recent assessments by the Central Groundwater Board, Government of India (CGWB 1995 and 2006) at two time points, 1995 and 2004. The comparability of these data sets is limited by two major factors: (a) changing administrative boundaries of districts; and (b) a slight change in the methodology of assessment in 2006. However, this data can be utilised to track the national scenario on groundwater use, over time. With these data sets, we now build a complete picture of quantitative and qualitative aspects of groundwater vulnerability in India. Vulnerability here implies potential danger to drinking water sources, either in terms of the quantity of water available or the quality of available water or a combination of both.

Available data shows that there has been a remarkable change in the groundwater scenario in the country even within a short span of nine years (1995-2004). On the basis of their stage of

Table 1: State-wise Status of Groundwater Resources (2004)

No	State	Billion Cubic Metres (BCM)			Stage of GW Development (Net Draft/Net Availability*100)
		Annual Replenishable Groundwater Resource	Net Availability	Net Draft	
1	Andhra Pradesh	36.50	32.95	14.90	45
2	Assam	27.23	24.89	5.44	22
3	Bihar	29.19	27.42	10.77	39
4	Chhattisgarh	14.93	13.68	2.80	20
5	Gujarat	15.81	15.02	11.49	76
6	Haryana	9.31	8.63	9.45	109
7	Jammu and Kashmir	2.70	2.43	0.33	14
8	Jharkhand	5.68	5.25	1.09	21
9	Karnataka	15.93	15.30	10.71	70
10	Kerala	6.84	6.23	2.92	47
11	Madhya Pradesh	37.19	35.33	17.12	48
12	Maharashtra	32.96	31.21	15.09	48
13	Orissa	23.09	21.01	3.85	18
14	Punjab	23.78	21.44	31.16	145
15	Rajasthan	11.56	10.38	12.99	125
16	Tamil Nadu	23.07	20.76	17.65	85
17	Uttar Pradesh	76.35	70.18	48.78	70
18	Uttarakhand	2.27	2.10	1.39	66
19	West Bengal	30.36	27.46	11.65	42
20	Other states	7.67	7.03	0.86	12
Total		432.42	398.70	230.44	58

Source: CGWB (2006).

groundwater development, we classify districts as "safe" and "unsafe" (districts in the "semi-critical", "critical" and "over-exploited" categories).[2] From Table 1 we can see that the proportion of "unsafe" districts in India has grown from 9% in 1995 to 31% in 2004. The area under "unsafe" districts has risen from 5% to 33% and population affected from 7% to 35% within this short span of nine years[3] (Table 2).

Table 2: Comparative Status of Groundwater Development (1995 and 2004, in %)

Stage of Groundwater Development*	Total Districts		Total Area		Total Population	
	1995	2004	1995	2004	1995	2004
0-50% ("Safe")	82	55	89	52	80	45
50-70% ("Safe")	10	15	7	16	13	20
70-90% ("Semi-critical")	4	13	2	14	3	17
90-100% ("Critical")	1	4	1	5	1	3
>100% ("Overexploited")	4	14	2	14	3	15
Total	100	100	100	100	100	100

Source: CGWB (2006).

The crux of the groundwater challenge in India is that there is extreme overexploitation of the resource in some parts of the country coexisting with relatively low levels of extraction in others. Thus, the stage of groundwater development in Punjab (145%), Rajasthan (125%) and Haryana (109%) have reached unsustainable levels while Tamil Nadu (85%), Gujarat (76%) and UP (75%) are fast approaching that threshold. Table 3 provides distribution of the districts in "safe" and "unsafe" categories in some selected states. The number of "unsafe" districts has increased from 33 in 1995 to 178 in 2004. Nearly all districts in Punjab, Rajasthan and Haryana are in the "unsafe" category. Seventy-two per cent of the districts in Tamil Nadu and nearly half the districts in Uttar Pradesh and Karnataka are also in unsafe category. While the traditional green revolution states of Punjab and Haryana continues to lead in terms of the proportion of area and population affected by groundwater overuse, what is perhaps more remarkable is that states like Rajasthan, Tamil Nadu and Uttar Pradesh are rapidly moving in the same direction of quantitative depletion of their groundwater resources.

The message is thus clear: there is definite evidence on increased pressure on aquifers[4] and the race to drill and pump. More districts and a larger proportion of population are going to get into the unsafe category unless the rate of groundwater extraction is regulated. It is, therefore, worthwhile to ask how safe are the so-called "safe" districts in terms of their groundwater usage. Using the share of groundwater in total irrigated

Table 3: Number and Proportion of 'Unsafe' Districts (GWD>70%) in Selected States (1995 and 2004, in %)

	Districts in Unsafe Category		State Area Affected		State Population Affected	
	1995	2004	1995	2004	1995	2004
Andhra Pradesh	0	27	0	27	0	26
Gujarat	5	40	2	56	4	44
Haryana	63	89	46	93	55	97
Karnataka	5	50	4	52	5	61
Madhya Pradesh	0	23	0	16	0	22
Punjab	50	94	43	95	52	97
Rajasthan	35	97	7	97	15	97
Tamil Nadu	29	72	24	73	23	77
Uttar Pradesh	0	49	0	47	0	55
West Bengal	0	18	0	15	0	24
All India	9	30	5	33	7	35

Source: CGWB (1995 and 2006).

area, we classify the districts as groundwater dependent districts and those which are not groundwater dependent. A groundwater dependent district is one where groundwater accounts for over 50% of the irrigated area. By comparing the level of groundwater dependence at the district level with the stage of groundwater development, we get a dynamic picture of the movement towards an impending crisis, which is going to hit us very soon.

As seen from Table 3, 30% (178 districts) out of the total 589 districts have reached the "unsafe" category. Another 149 districts (25%) have a safe level of groundwater development *today* but have high groundwater dependence. It is likely that many of these districts will very soon move into the unsafe category. A subset of 65 districts (11%) out of the latter already has levels of groundwater development in the range of 50-70%. With their high dependence on groundwater for irrigation, we can predict that these districts are soon going to join the "unsafe" category, worsening an already serious crisis. While making a strategy of sustainable management of groundwater, we must take into account the dynamic situation where, with uncontrolled exploitation of groundwater resources, more and more districts and blocks will enter the danger zone soon. The quick change of situation between 1995 and 2004 should be taken as a warning of an impending catastrophe ready to strike in the near future.

The problem needs urgent attention because groundwater is the major source of drinking water especially in rural areas. According to the latest available data from the National Sample Survey, 56% of the rural households get drinking water from handpumps or tube wells, 14% from open wells and 25% from piped water systems based on groundwater (NSSO 2006). According to the department of drinking water supply (DDWS), GOI, nearly 90% of the rural water supply currently is sourced from groundwater. Though the share of drinking water in total water use is about 7% while irrigation accounts for over 80%, rapid expansion of groundwater irrigation can threaten drinking water security in the long run, since the resource for both uses is common. Indeed, there is mounting evidence that this could be happening in many parts of rural India, as revealed through the statistics of several habitations "slipping back" from full coverage to partial coverage.

The National Drinking Water Mission claimed in 1996 that only 63 problem villages were left which had no access to safe drinking water. This figure was later revised in 1999 and a new target was set for universal coverage of 15 lakh habitations by the end of the Tenth Five-Year Plan. According to the DDWS (2006), the number of "slipped-back habitations" to be recovered between 2005 and 2010 had grown to 4,19,034. The Eleventh Plan document reports that 2-3% of the habitations have slipped back, bringing down the coverage from 92% in 2003 to 89% in 2007 in rural areas (Planning Commission 2008). The most important single reason for this slippage is the "drying up of the source", which is a reflection of the decline in water levels on account of increased groundwater extraction (Shankar and Shah 2009). Such decline, among other impacts, is severely felt during the summer months, when acute drinking water scarcity hits villages and even tanker supplies are constrained in regions of extensive overexploitation. Thus, the final result of the extraction of groundwater in excess of annual recharge is that our drinking water sources start drying up, affecting the lives of millions of people.

3 Water Quality Considerations

The question of safety of the level of groundwater development in a district or block can be approached from another angle – that of water quality. Even while a district may be "safe" in terms of quantitative availability of groundwater, it is possible that it also has a high incidence of water quality problems. Official figures from DDWS state that out of 593 districts from which data is available, we have problems from high fluoride (203 districts), iron (206 districts), salinity (137 districts), nitrate (109 districts) and arsenic (35 districts) (DDWS 2006).[5] Biological contamination problems causing enteric disorders are present throughout the country and probably constitute the problem of major concern, being linked with infant mortality, maternal health and related issues such as loss of valuable "work time". However, no clear estimates are available on the impact of this problem. It must be noted, however, that this summary is based on a sketchy nation-wide data and represents only the tip of the iceberg of water quality problems. The reality could be much grimmer than what is apparent here[6] (Table 4).

Let us now look at the overall picture. As seen above, 178 districts (30%) have "unsafe" levels of groundwater development. Many of these also have severe water quality problems, but we will not go into this issue here and instead focus on those districts considered "safe" in quantitative availability of groundwater. Among these "safe" districts, as many as 169 districts have at least one of the three most serious water quality problems (arsenic or fluoride or salinity). 128 districts among these "safe" districts have high fluoride, 40 have arsenic problem, 80 have high salinity and 175 have high incidence of iron. Taking together these 169 districts with water quality problems to the 178 districts with "unsafe" levels of groundwater development, we find that a total of 347 districts (59% of all districts in India) have problems related to either the quantitative availability or quality of groundwater (Table 5). This clearly indicates that the optimism often found in government documents that most habitations in India have achieved water security is totally misplaced.

It is now pertinent to ask why vulnerability of this magnitude gets ignored at the policy level. One reason could be that the groundwater overuse is often perceived as a localised problem, largely confined to the water-deficient regions. In the so-called "water-abundant" regions (for instance, in eastern India), the way forward suggested is an aggressive utilisation of available water resources for a direct attack on poverty. This view needs to be tempered with the recognition that ultimately even the high rainfall regions do not have unlimited supplies of water. Their perceived water surpluses are largely on account of low utilisation of available water resources, which could rapidly disappear once

Table 4: Estimated Order of Magnitude (Districts and Population Affected) and Impact of Drinking Water Quality Problems in India

Quality Problems	Number of Districts	Estimated Population Affected/Exposed	Cause	Impact
Salinity	137	No estimates available	Inherent (geogenic)/Man-made (e g, coastal saline intrusion due to overpumping)	Kidney stones due to poor hydration in such areas (Cost per family Rs 7,500 per year)
Fluoride	203	65 million	Inherent (geogenic), but aggravated also by over-exploitation; increased by malnutrition	Fluorosis; DALY= 38.5 per 1,000 population; Cost per capita >Rs 5,000 per year
Arsenic	35	5 million in West Bengal; even more but unestimated in Assam, Bihar	Complex geogenic processes not yet well understood; but suspected to be related to excessive use and related water table fluctuations; increased by malnutrition	Arsenicosis ; DALY= 5-27 per 1,000 population; skin lesions, in extreme cases leads to cancer of lung and bladder
Iron	206	No good estimates	Geogenic mainly	Iron overload; cirrhosis; suspected diarrhea linkages; cardiac linkages
Biological	No good estimates	No good estimates	Related to poor sanitation and hygiene practices; increased by malnutrition	Diarrheal problems; DALY > 22 million years annually; total 4,50,000 deaths annually
Agro-chemicals	No good estimates	No good estimates	Related to pesticide/fertiliser use in agriculture	Multiple impacts; not understood well
Industrial effluents	No good estimates	No good estimates	Due to effluents from industries	Multiple impacts; not understood well

Source: S Krishnan (2009).

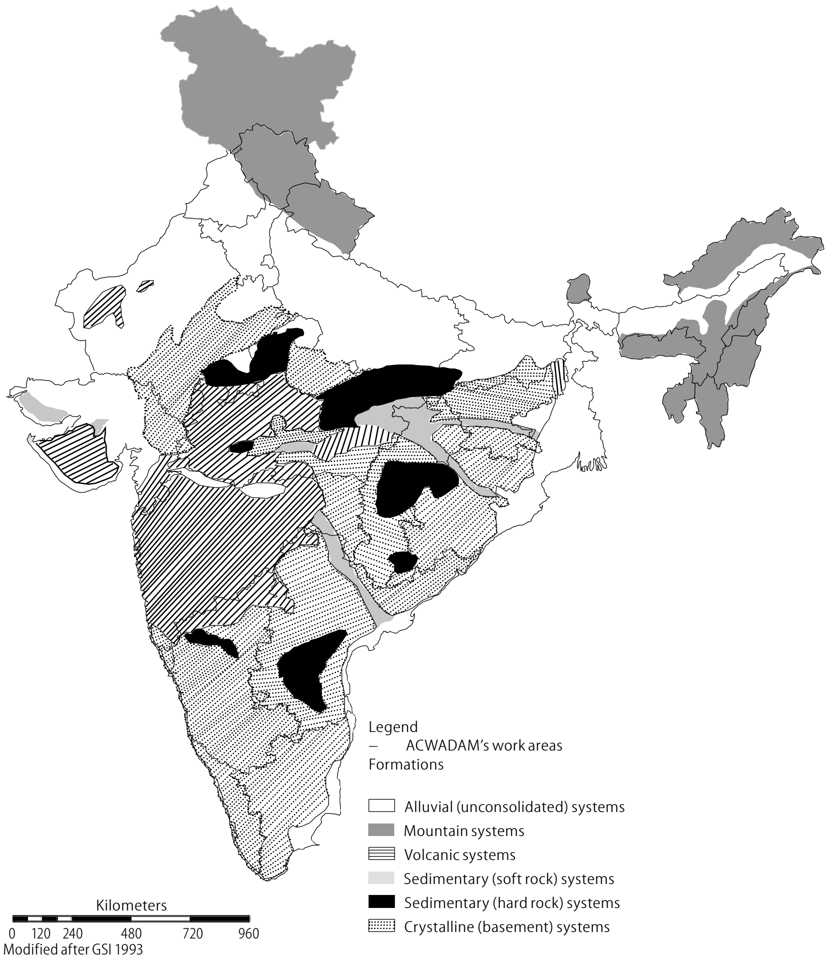
Table 5: Extent of Drinking Water Vulnerability in India

Description	Number of Districts	Percentage of Total Districts	Major States Where These Districts Are Located
1 Districts with High Level of Groundwater Development (GWD>70%) ("Unsafe" districts)	178	30	Punjab, Haryana, Rajasthan, UP, Gujarat, Tamil Nadu
2 Districts with Low Level of Groundwater Development (GWD<70%) but with Water Quality Problems			
a Fluoride	128	22	Rajasthan, Gujarat, Madhya Pradesh, Karnataka
b Arsenic	40	7	West Bengal, Karnataka, Maharashtra
c Nitrate	62	11	Assam, Gujarat, Maharashtra, Rajasthan, Kerala
d Salinity	80	14	Assam, Haryana, Kerala, Gujarat, Rajasthan, Orissa
e Iron	175	30	Assam, Bihar, Chhattisgarh, Kerala, Orissa
f Biological contamination	No clear data available		
g At least one of the three most serious quality problems (arsenic or fluoride or salinity)	169	29	Assam, Gujarat, Haryana, Karnataka, Maharashtra, Madhya Pradesh, Orissa, Rajasthan, Uttar Pradesh, West Bengal
Total (1+2g)	347	59	

Source: Kulkarni et al (2009).

Map 1: Hydrogeological Settings along with State and District Boundaries (Developed from GSI 1993; CGWB 2006; COMMAN 2005) – by ACWADAM

Overlay of generalised hydrogeological settings on administrative boundaries (districts and states)



Source: Kulkarni et al (2009).

diffusivity (the relationship between storage and transmissivity) are secondary or missing from the current, highly aggregative methods of assessment. The vast geological diversity in India renders the study of aquifers a challenging task. Still, such a study is required because it is the behaviour of the aquifer that dictates the approaches to managing groundwater resources and addressing vulnerability at a local level.

4 Delineating Groundwater Typologies

Conventional approaches to understanding groundwater resources involve geological provinces describing the broad physical characteristics of regional geological systems (Karanth 1987; Kulkarni 2005; CGWB 2006). These maps describing the physical settings in which groundwater accumulates and moves need to be further disaggregated to make them useful for local situations. As a starting point to move towards a more disaggregated picture, we have developed a map of hydrogeological settings in India by combining information available from various sources.[7] Using a GIS framework, the hydrogeological map of India was overlaid onto the state and district boundaries. Further overlay of the map of India showing the semi-critical, critical and overexploited units prepared by CGWB onto this hydrogeology map resulted in a more disaggregated regional hydrogeological settings map (Map 1). Based on this map, we have also classified states that fall into the six broad categories of regional hydrogeological settings. The percentage share of each setting to the total area of the country is also shown in Table 6 (p 42).

We can, thus, see that the hydrogeological setting is highly complex in many states. Some hydrogeological settings (such as the alluvial and crystalline rocks settings) span many states, districts and blocks. On the other hand, many districts in some states (Madhya Pradesh, Gujarat and Andhra Pradesh) have more than one hydrogeological setting. Given this diversity, the usefulness of the CGWB's categorisation of districts/blocks as "safe", "semi critical", "critical", "overexploited", etc, needs to be fundamentally questioned. As the processes of groundwater accumulation and movement are vastly different across geological types, the implications of any stage of GWD will vary significantly with each type. We cannot have the same classification of the stage of GWD for settings 2 and 3 (alluvial and soft sedimentary systems) on the one hand and settings 1 and 4-6 (mountain, volcanic, crystalline and hard sedimentary systems) on the other. Thus, a much lower stage of GWD in the latter (covering 71% of India's land area) could be as "unsafe" as a comparatively higher level in settings 2 and 3. Hence, we need to exercise far greater caution in groundwater use in settings 1 and 4-6. It follows that we

the scale of utilisation is stepped up. Hence, even while emphasising the need to intensify groundwater use in the high poverty states of eastern India, we must be careful to caution ourselves that such intensification is to be attempted within a framework that does not threaten the sustainability of the resource. The experience of the last decade should act as a grim reminder as to how quickly a turnaround can take place in the groundwater scenario.

Equally important seems to be the problems with the current methodology of estimation of groundwater potential. The methodology of assessment of groundwater in India follows either the rainfall infiltration method or the groundwater level fluctuation and specific yield method as recommended by the Groundwater Estimation Committee (GEC 1997). The primary basis for classification of assessment units is the relationship between pumping and annual replenishment of groundwater. This provides an incomplete picture because the relationship between pumping and annual replenishment is also shaped by the characteristics of the rock strata (or *aquifers*) in which groundwater occurs. The aquifer is the natural unit within which groundwater occurs. Moreover, one cannot presume that the aquifer boundaries will overlap with the administrative boundaries of a district or a block. Aquifer characteristics, such as storage, transmissivity and need to develop a *disaggregated picture of groundwater accumulation through* a *micro-level aquifer mapping* of the whole country.

More detailed mapping exercises are required to customise these broad regional hydrogeological settings to local situations to identify location-specific groundwater typologies and associated responses. The complex issue at this stage is the relevant *scale* at which mapping needs to be done and interventions coordinated. The appropriate scale is determined by the degree of interconnections between aquifers and the extent to which actions done in one part of the aquifer affects other parts. Here the science of hydrogeology plays a crucial role in generating the necessary knowledgebase. *Alluvial systems* in general have recharge cycles at a regional scale and also on a different time-scale, with groundwater occurring in multiple aquifers (an aquifer is overlain by many villages, also each village can vertically tap parts of multiple aquifers). Quality issues here could escalate exponentially along with depletion, some with irreversible effects. In such situations, aquifer systems need to be mapped at the scale of small river basins (size 500-1,000 km^2) and appropriate strategies worked out for conservation and recharge at this scale. *Crystalline formations ("basement rocks")* can have recharge systems that are local in nature and depletion here tends to be more on the quantitative side. Interventions need to be coordinated at the scale of milli-watersheds (100 km^2) with emphasis on tuning strategies of conservation and recharge to the local dynamics of water availability and quality. At the other extreme, we can have the *mountain systems* with extremely localised recharge, where the appropriate scale of mapping and intervention is that of a micro-watershed (1-10 km^2). Aquifer mapping at this scale would emphasise strategies of conservation and recharge to be oriented mainly towards local recharge-discharge balances (Kulkarni et al 2009) and particular emphasis on conserving and protecting spring systems.

Aquifers seldom exist in isolation. The complex layering of rock strata with varying aquifer properties gives rise to specific *groundwater typologies*. We must remember that while the bio-physical structure is often useful in identification of properties of rock strata, the groundwater typologies are not just entities in physical space. They go with a historically governed pattern of access to groundwater and the social processes that regulate its use. Identification of typologies becomes more complex when we introduce considerations of water quality into the discussion. Thus, while the physical structure broadly sets out the range of options available, the trajectory of development of groundwater resources in a specific historical context is governed by the social processes and the choices made therein. Hence, groundwater typologies need to be seen as a *socio-physical category*.

The basic idea emerging from the above is that groundwater in an aquifer is a common pool resource, to be managed as a community resource, even when access to it is private. Groundwater is an invisible, non-stationary, "fugitive" resource, which does not respect boundaries set by landholdings. Clearly, the water below "my" land is not "mine" because it may flow from below my neighbours' lands and even from areas that fall beyond "my" village boundaries. This follows from the connectivity of the aquifer cutting across field boundaries and administrative divisions. By lowering the depth of his tube well, my neighbour can squeeze all the water not just out of my well but from much larger portions of a "common" aquifer. And by increasing the horsepower of my pump and running it for more number of hours, I can draw more water to irrigate my sugar cane field. The spillover of the consequences of my actions to my neighbours is determined by the connectivity of the aquifers. From this perspective, we need to adopt strategies that ensure the sustainable and equitable use of groundwater by the entire user community. The primary concern here is that of protection of the resource, with a clear idea of the annual inflows to and outflows from the groundwater system. The notion of the groundwater community goes beyond the "village" and embraces all those who draw water from the aquifer in question.

Table 6: Hydrogeological Setting – Details of Areas and Distribution (States)

Hydrogeological Setting	Area (km^2)	States	Percentage of Total Area
Mountain systems	5,25,067.107	Arunachal Pradesh, Assam, Haryana, Himachal Pradesh, Jammu and Kashmir, Manipur, Meghalaya, Mizoram, Nagaland, Rajasthan, Sikkim, Uttar Pradesh, Uttarakhand, West Bengal (Total: 14 states)	16
Alluvial (unconsolidated) systems	9,31,832.5	Arunachal Pradesh, Assam, Bihar, Delhi, Diu & Daman, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Kerala, Madhya Pradesh, Maharashtra, Orissa, Pondicherry, Punjab, Rajasthan, Sikkim, Tamil Nadu, Uttar Pradesh, Uttarakhand, West Bengal (Total: 21 states)	28
Sedimentary (soft) systems	85,436.2341	Andhra Pradesh, Chhattisgarh, Gujarat, Madhya Pradesh, Maharashtra, Orissa, Jharkhand, West Bengal (Total: 8 states)	3
Sedimentary (hard) systems	1,94,797.572	Andhra Pradesh, Bihar, Chhattisgarh, Jharkhand, Karnataka, Madhya Pradesh, Orissa, Rajasthan, Uttar Pradesh (Total: 9 states)	6
Volcanic systems	5,25,035.867	Andhra Pradesh, Bihar, Dadar & Nagar Haveli, Diu & Daman, Gujarat, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Uttar Pradesh, West Bengal (Total: 13 states)	16
Crystalline (basement) systems	10,23,639.2	Andhra Pradesh, Bihar, Chhattisgarh, Goa, Gujarat, Haryana, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Pondicherry, Rajasthan, Tamil Nadu, Uttar Pradesh, West Bengal (Total: 17 states)	31

Source: Kulkarni, et al (2009).

5 Framework for Sustainable Groundwater Management

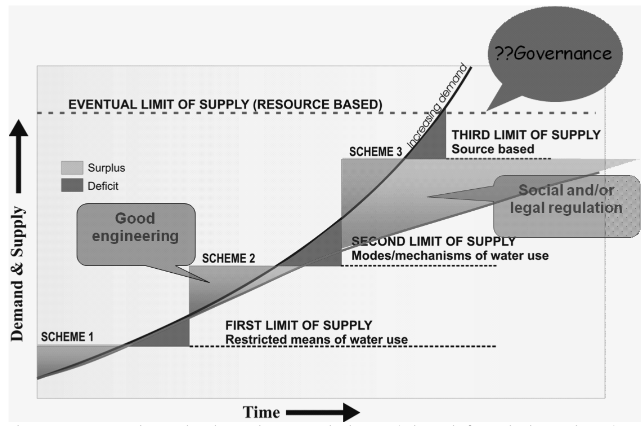
As discussed in the previous section, the first step in sustainable management of groundwater is to carefully construct a disaggregated picture by mapping aquifers and delineating aquifer typologies incorporating variations in hydrogeological and socio-economic contexts (Kulkarni and Shankar 2009). Ideally, aquifer mapping should take place at the scale of watersheds of the order of 1,000 to 2,000 hectares. These maps can be then aggregated at a more regional scale rather than move down from an aggregated picture. Along with mapping, we also need to build a comprehensive database on the groundwater flow systems and groundwater availability in each hydrogeological setting.

This database should enable a real time monitoring of the status of groundwater use and implementation of remedial measures in cases where the resource is threatened with depletion. Such efforts need to be dovetailed with the Development of Water Resources Information System scheme (implemented by the CWC and ISRO), which aims to put in place a web-enabled water resources information system. Eventually, we need to bring this information support to the watershed and village-level, which could enable the village communities and their institutions to take informed decisions about their water resources.

Emphasising the need to maintain groundwater balance, the Planning Commission's Expert Group has spoken about the need for "adopting for all groundwater management units a sustainable-yield management goal, which means that average withdrawals should not exceed long-term recharge" (Planning Commission 2007: 47). In other words, this goal is the absolute limit imposed by the nature of the resource and which should not be violated. Disaggregated aquifer maps and database management system will make it possible to determine this sustainable yield management goal for each aquifer and watershed in a given hydrogeologic setting. This gives us the quantum of groundwater available that is to be apportioned between competing uses and users. The next step, therefore, is to define a broad set of priorities of water use at an aquifer or watershed level attempt to shape the existing use pattern to suit these priorities. This involves working out *location-specific protocols* and agreements within the user community for sustainable use of water. These protocols emphasise *drinking water security* as their primary objective. Sustainable use of groundwater involves adoption of norms related to enhancing recharge through protection of the recharge area, controlling the depth and spacing of wells, regulating capacity and efficiency of pumps used, water-saving irrigation methods and overall regulation of cropping pattern to rationalise water use in agriculture. Clearly, implementation of these strategies is not a technical planning exercise. These are not fixed solutions frozen at a point in time, but rather an evolving set of rules emerging from a continuous and active dialogue within the community of users. These rules are facilitated and supported by a scientific understanding of the characteristics of the resource (Kulkarni and Shankar 2009).

These location-specific protocols offer a menu of options both on the supply and demand side of management of water in the aquifer system. We must remember that however much water we may conserve and collect, it will prove inadequate unless we carefully scrutinise uses to which water is put. The fundamental binding constraint is really provided by the demand side. Hence, demand regulation is as integral a part of this effort as supply augmentation through recharge. Figure 3 provides a schematic view of the relationship between availability, demand and supply of groundwater in any region. The availability (within a hydrologic/hydrogeologic unit) defines the upper limit for demand and supply. In the case of groundwater, availability can be defined as the environmentally sustainable withdrawal of groundwater that the aquifer can support. In many rural areas of India, a single village usually has different episodes of supply augmentation – in other words, water supply schemes or well excavations that simply try to keep a pace with the ever-increasing demand. Most supplies are engineering techno-fixes that cater to a certain "demand range". Hence, they work for a certain period in time, after which demand outstrips the supply range and a deficit is created, for which another scheme (supply-step) is created. Each supply, as Figure 3 illustrates, has a fixed time frame and is inexorably driven by the uncontrolled growth in demand.

Figure 3: Conceptual Diagram Illustrating Demand, Supply and Availability with Regard to a Resource



Chasing increasing demand with supply-oriented schemes (adapted after Kakadae et al 2001)
Source: Kulkarni et al (2009).

With demand continuously on the rise, it would eventually outstrip supply when all available (local) supply options are exhausted. This would necessitate getting water from "external" sources, needing transfer of water across large distances. The extreme example of this is the proposal for interlinking of rivers and transfer of water across basins. We have also seen this situation in many urban areas of the country, especially with respect to drinking water and now see the same situation gradually unfolding in many rural areas as well. Figure 3, however, also shows that with active social regulation and management of groundwater, the demand could be regulated (light green line) in such a way that it remains within the ecological boundary of available supply. In other words, with demand management, a water supply scheme in a village or a town tends to run over a longer period of time, a simple conceptualisation of sustainability. This conceptualisation sets the theme for a strong articulation of demand management of groundwater in the current Indian context. The conceptualisation itself includes availability or resource pool as a basis to think about sustainability. The concept therefore also poses the question of resource governance going beyond regulating demand and managing supply; groundwater governance, we believe, comes down to understanding the resource – the aquifer in this case.

The above diagram attempts to illustrate a broad concept, based on the question of quantity of groundwater. Groundwater quality is of equal importance too. For instance, under certain hydrogeologic conditions, a depleted aquifer would also imply deterioration in groundwater quality. Although recharge is considered today as a magic wand diluting the contaminants, a certain degree of caution is to be exercised with respect to groundwater quality. The mandate for monitoring groundwater quality data would need to consider appropriate links to drinking water, public health and even to the use of groundwater in agriculture and industry. An aquifer-based approach will be able to then define the boundaries of observation and basis for analysis. These data could then be aggregated at required spatial (village/district) or temporal (monthly/yearly) intervals.

Backed by aquifer-level mapping and database support, several groundwater management pilots could be initiated in different hydrogeological settings of the country. Each of these pilots could cover an area of 5,000 to 10,000 ha or boundaries of an aquifer, whichever is less. Some of these pilots could focus on the critical and overexploited blocks of the country with the objective of drawing up a comprehensive programme of aquifer management to address the crisis. The lessons learnt here could be scaled up to cover a larger number of blocks later. For better results, these pilots sought to be designed so that they converge seamlessly into ongoing programmes like MGNREGA, IWMP, artificial recharge, etc. Convergence with ongoing drinking water and sanitation projects also becomes significant in this regard. The scourge of water initiatives in India has been sectoral compartmentalisation, with very little interaction across sectors. This needs to be broken down and then built up into a more robust manner of integrated thinking on water to emerge.

Implementation of strategies for sustainable management of groundwater also involves a rearticulation of the legal framework on groundwater. In recent years, several state governments have enacted their own groundwater laws. The common problem with all these pieces of legislation is their excessive reliance on the command-and-control mechanism. In a country with a multitude of users scattered across a wide landscape and with unregulated access to groundwater, such an approach has very little chance of success. Indeed, cooperative management by the user communities is the only available option (Planning Commission 2007). Equally important, the legal framework needs to be sensitive to the common property aspect of groundwater. In its landmark judgment on the Coca Cola case (*Perumatty Grama Panchayat vs State of Kerala*), the Kerala High Court declared,

> The state is the *trustee of all natural resources* which are by nature meant for public use and enjoyment. Public at large is the beneficiary of the sea, shore, running waters, air, forests and ecologically fragile lands. The state as a trustee is under *a legal duty to protect the natural resources*. These resources meant for public use cannot be converted into private ownership" (emphases added).

Acceptance of this public trust principle implies that the right to water is to be separated from the right to land. The recently enacted Andhra Pradesh Water, Land and Trees Act (APWALTA) and the proposed Maharashtra Groundwater (Development and Management) Bill, 2009, empower the state to act as the trustee of public good and interfere with individual rights wherever it comes into conflict with public interest. However, keeping in mind the grim situation of groundwater in some states, this common property aspect needs much clearer emphasis in the state acts.

6 Conclusions

Recent data on the status of groundwater resources in India reveal several alarming trends. The rate of withdrawal of groundwater has reached "unsafe" levels in 31% of the districts, covering 33% of the land area and 35% of the population. The situation has dramatically worsened within a short span of nine years, between the assessments done in 1995 and 2004. Further, many of the so-called "safe" districts have severe problems of water quality, which threatens their drinking water security. Taking quantitative and qualitative aspects together, it would appear that a total of 347 districts (59% of all districts in India) are vulnerable in terms of safe drinking water in India. This is a matter of serious concern, requiring a new approach.

This paper has tried to outline a new approach to groundwater based on an aquifer management framework. Groundwater is an open-access, common pool resource. Hence, protection of the resource is not possible unless the users agree to cooperate and manage the resource themselves in a sustainable manner. Forging major partnerships between government departments, local self-government, people's institutions and the civil society organisations holds the key to initiating *scaled* approaches to groundwater management. A command-and-control system is not going to work. The state and groundwater legislations need to play the role of a facilitator of such partnerships and promoting cooperative community action. The challenge of groundwater governance in India is, first, to support and empower the community-based systems of decision-making and, second, to re-engineer the existing legal framework and groundwater management institutions to support and foster community action.

We believe the actions listed below forms a clear beginning to a fresh approach to addressing the groundwater challenge in India:

- A review of the current methodology of assessment of groundwater resources, bringing in an aquifer basis to the assessment.
- Comprehensive mapping of aquifers and monitoring groundwater quality at appropriate scales in the various hydrogeologic settings described in this paper.
- Developing typologies of groundwater resources in India as the basis for a national level groundwater management programme.
- Prioritisation of domestic water security within a strategy to implement the groundwater management programme above.
- Setting up a robust and transparent groundwater data collection and sharing mechanisms, mainly as decision support tools in programme implementation and monitoring.

NOTES

1 Level (or stage) of groundwater development is the ratio of gross annual groundwater draft for all uses to net annual groundwater availability. Net annual groundwater availability is defined as the annual groundwater potential (total annual recharge from monsoon and non-monsoon seasons) minus the natural discharge during non-monsoon season (estimated at 5-10% of the total annual groundwater potential).

2 When the value of the stage of groundwater development of an area (district or block) is less than 70%, it is considered safe; between 70% and 90%, it is considered semi-critical; between 90% and 100% it is identified as critical; and more than 100% is considered overexploited. It is the stage of development of an area along with the long-term decline in either pre- or post-monsoon water levels that makes it semi-critical, critical and overexploited (CGWB 2006).

3 We must remember that part of this change is also due to the reformed methodology of estimation and newer, improved data-sets. However, the contribution of this to the overall result is likely to be small.

4 An aquifer is described as a rock or rock material that has the capacity of storing and transmitting water such that it becomes available in sufficient quantities through mechanisms like wells and springs.

5 This water quality information from the DDWS is really in the form of habitation level data, specifying limits of certain groundwater quality parameters. This data is useful, to a limited extent, but certainly not enough for a national level strategy to counter groundwater contamination. In fact, much of the data (for instance, bacteriological, nitrate and fluoride) are simply in the form of a "positive/negative" values indicating contamination but without as much a reference to the seasonal effects, trends within a particular hydrogeological setting and even patterns of contamination across a particular area or region.

6 Data is collected on groundwater quality to determine whether it is within safe limits for a specific purpose such as domestic use. The dynamics related to groundwater contamination – health, food and migration in space and time – are currently missing from mainstream groundwater planning. Aquifer level geochemical studies on specific local contaminants and their transport and transient nature would add value to aquifer based studies.

7 This map is based on the map of geology of India (GSI 1993), major aquifers of India (www.cgwb.org), other sources (COMMAN 2005) and on the basis of ACWADAM's own work in different parts of India.

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