Groundwater management through the 'commons' lens: recognizing complexity

Himanshu Kulkarni[1]

ABSTRACT

The complex nature and diverse contextual regime of groundwater problems in India compel the development of a strategic approach to groundwater management. The complexity itself is due to the wide diversity not only in the hydrogeological framework that defines the accumulation and movement of groundwater in different physical settings, but also in the social and economic drivers that determine groundwater use patterns and changes therein through a time-line. India is divided into six or seven different 'settings' to understand the complexity. Each setting can be described based on hydrogeological systems (including the variability within one setting), the social-economic factors that are influenced by (and which, in turn influence) groundwater resource status and response strategies adopted by policy makers and communities to mitigate groundwater related challenges. Clearly, each setting warrants a strategic outlook if groundwater is to be managed on a 'commons-basis'.

The development of strategies to respond to groundwater over-use and deteriorating groundwater quality require a 'process-based' approach, wherein there is a need to redefine the institutional structure that looks into groundwater problems in India. The process-based approach has many advantages over the current 'institutional silo' approach. First, it begins with a principle: the principle of perceiving groundwater resources under the category '*commons*'. Further, 'processes' are central to addressing groundwater problems and do not necessarily involve one-off solutions that are expected to constitute a 'pill for all ills'. Second, strategy development can happen efficiently only in a 'phased' manner, with each strategy subject to adaptation and refinement as experience is gained.

[1] Advanced Center for Water Resources Development and Management (ACWADAM), Plot 4, Lenyadri society, Sus road, Pashan, Pune-411021. Email: acwadam@vsnl.net

INTRODUCTION

A lumped picture of groundwater development and quality is useful to understand 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 as a compounded effect. When one brings aggregated district-level data on groundwater use and quality patterns, the following broad picture emerges (Table 1).

Table 1: Extent of Drinking Water Vulnerability in India (after CGWB, 2006; DDWS, 2009; Kulkarni et al, 2009a)

Description	**Number of districts**	**Percentage of total districts**	**Major states where these districts are located**
1. Levels of Groundwater Development			
a. Districts with High Level of Groundwater Development (GWD>70%) ("Unsafe" districts)	173	29%	PUNJAB, HARYANA, RAJASTHAN, UP, GUJARAT, TAMIL NADU
b. Districts with Medium Level of Groundwater Development (GWD 50%-70%) but with High	65	12%	MADHYA PRADESH, MAHARASHTRA, UP, TAMIL NADU, GUJARAT, BIHAR
2. Districts with Low GWD but with Water Quality Problems			
a. *Fluoride*	128	31%	RAJASTHAN, GUJARAT, MADHYA PRADESH, KARNATAKA
b. *Arsenic*	40	10%	WEST BENGAL, KARNATAKA, MAHARASHTRA
c. *Nitrate*	62	15%	ASSAM, GUJARAT, MAHARASHTRA, RAJASTHAN, KERALA
d. *Salinity*	80	19%	ASSAM, HARYANA, KERALA, GUJARAT, RAJASTHAN, ORISSA
e. *Iron*	175	43%	ASSAM, BIHAR, CHHATISGARH, KERALA, ORISSA

e. *Iron*	175	43%	ASSAM, BIHAR, CHHATISGARH, KERALA, ORISSA
f. *Biological contamination*	NO CLEAR DATA AVAILABLE		
g. *THREE OR MORE PROBLEMS*	131	32%	ASSAM, GUJARAT, KARNATAKA, KERALA, MAHARASHTRA, MADHYA PRADESH, ORISSA, RAJASTHAN

Taken together, it would appear that water vulnerability is now visible in at least 60-70% of the districts of the country. It is not surprising that, under such a scenario, water security, especially household water in much of rural India remains a constant threat, with a constant 'slip-back' of habitations to pre-water supply scenarios. So, not only is the problem of groundwater restricted to that of over-use in agriculture, but within or outside the problem of groundwater overexploitation is the problem of groundwater quality, endangering the basic life-need, that of *potable drinking water*. However, given the *fugitive* character of groundwater resources and the *uncertainty* in their prediction, simply reserving or protecting drinking water supply is quite challenging. Hence, protecting a small proportion of good quality water (for drinking and other domestic uses) is not as simple as it seems. It is about a larger process of groundwater management, about identifying the right units for such management and the scales of operation of such management.

INDIA'S GROUNDWATER DIVERSITY

The extent of groundwater overexploitation is quite diverse across the country. This means that while there are swaths of rampant groundwater exploitation, there are also contiguous regions where groundwater abstraction is quite limited. However, such a statement poses an interesting dichotomy: while on one hand there is scope to follow a conventional model of *dig, drill and pump* groundwater in areas where groundwater pumping is limited, the potential hazard of groundwater overexploitation, especially given the small-farmer context, looms large over major regions of the country. What has caused such large-scale exploitation of groundwater resources? Three very clear causes are stated (and accepted) for overexploitation impacts. These are:

1. An ever growing demand for groundwater – mainly from within agriculture, but increasingly now from growth in industrialization and urbanization.
2. The economics of crop-choice and intensification have not always matched the availability of groundwater resources.
3. The power-subsidy regime has sometimes promoted (user-end) and often prompted (supplier-side) uncontrolled pumping of groundwater.

Hence, groundwater overuse is a problem that remains mired in issues pertaining to a constant race between supply and demand, with the impacts felt on a resource, whose characteristics remain poorly understood. Understanding the resource, therefore, becomes one of the basic factors governing the processes of

[2] An aquifer is described as a rock or rock material that has the capacity of storing and transmitting water such

groundwater management. This argument clearly sets the ground for a more focused approach to understanding groundwater resources.

Problems surrounding groundwater overuse are not just a matter of the share of pumping to the annual replenishment; the relationship between these two important parameters is complex and depends upon the “aquifers” from which groundwater is tapped by wells, tube wells and bore wells; and, in many cases, which supply water to springs (Kulkarni et al, 2009a). The fundamental basis for good groundwater management is a clear understanding of aquifers[2]. Proper understanding of the geology in an area– rock types and rock structure – forms the fundamental basis to understanding aquifers, and therefore, in understanding groundwater resources. The geological diversity in India makes aquifer understanding challenging, but all the more important because the local situation, which dictates the approaches to managing groundwater resources, is crucial (Kulkarni, 2005). Moreover, local situations also determine the implications of groundwater overuse, droughts, floods etc. on how drinking water security is affected, a factor of immense significance in India, where some 90 to 95% of rural habitations depend on groundwater.

Currently, we are able to look at the national groundwater development scenario at the scale of a “unit” (usually a *block or taluka or mandal* – a subdivision of a district; in some cases, watersheds). Diversity in hydrogeological conditions is significant in India, even when one considers the national, aggregated geological picture. ACWADAM combined information available from various sources that gave an idea of the geological systems in India. Based on the map of geology (GSI, 1993), major aquifers of India (www.cgwb.org), other sources (COMMAN, 2005) and ACWADAM’s own work in different parts of India, a generalized map of “regional hydrogeological settings” was prepared (Figure 1). The map presents an aggregated picture, setting forth a broad geographical typology of hydrogeological conditions represented by broad categories of somewhat typical groundwater conditions. The hydrogeological settings overlay was prepared on the State and District boundary map of India, using a GIS framework,.

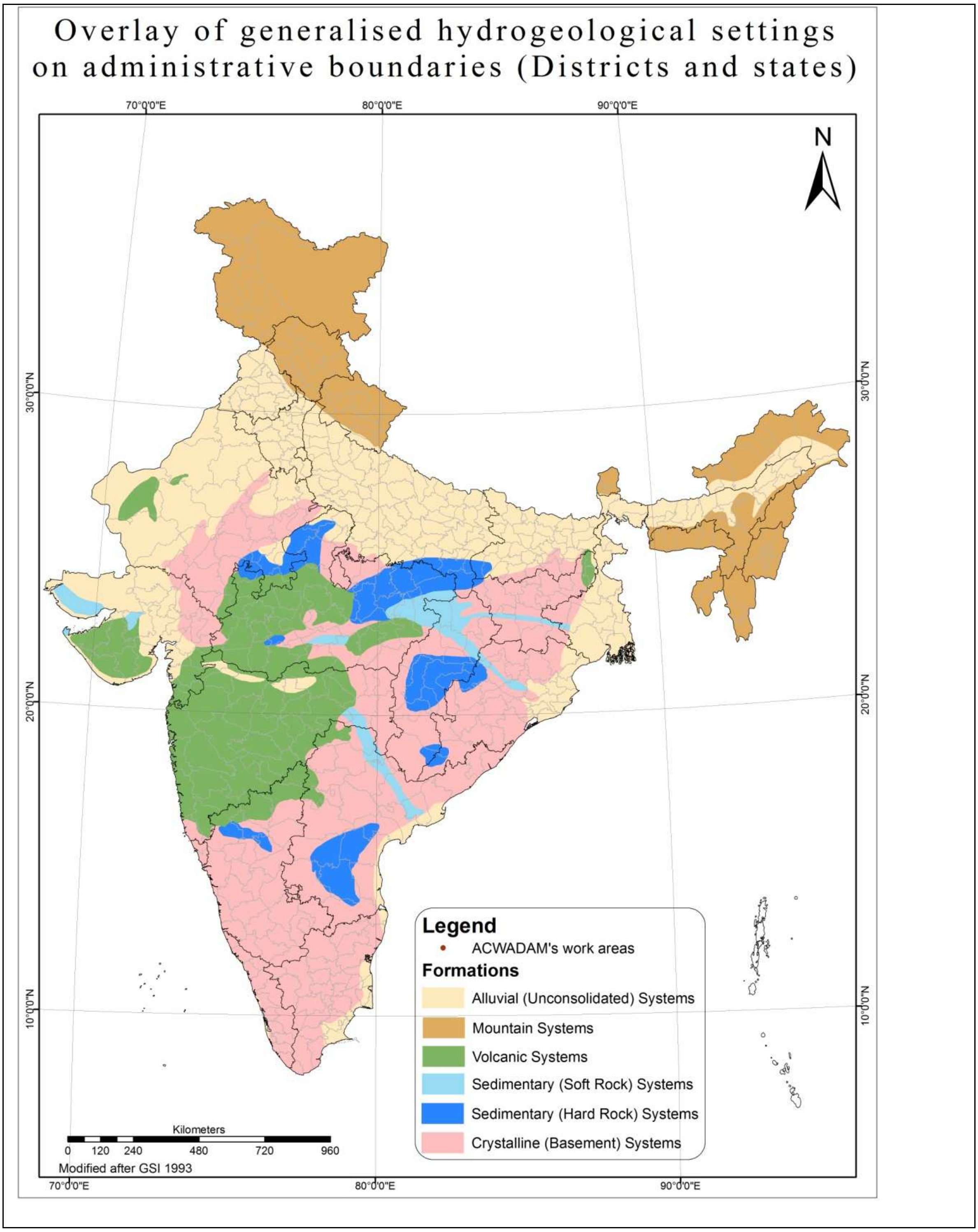
Figure 1 and Table 2 (derived through a GIS analysis) present a typology of the six broad hydrogeological settings in India. Even at an aggregated level, it is interesting to look at the relationship between these hydrogeological settings (representing aquifer systems) across India, especially in relation to the states and districts. It is clear from the map that most of the larger states in India have mixed hydrogeological settings, wherein the very logic of safe versus unsafe stages of groundwater development would have different connotations (Kulkarni et al, 2009a). About 71 % of India’s area is underlain by formations that include “consolidated rock” (the non-alluvial settings in Table 4). The remaining 29% is unconsolidated alluvium – loose rock material formed due to processes of weathering, erosion and deposition and not yet having consolidated into “rock”. Again, of the consolidated rocks, ‘hard rocks’ is a generic term applied to igneous and metamorphic rocks with aquifers of low primary intergranular porosity (e.g., granites, basalts, gneisses and schists) – settings 5, 6 and part of 1. Groundwater resource in hard rocks is characterised by limited productivity of individual wells, unpredictable variations in productivity of wells over relatively short distances and

that it becomes available in sufficient quantities through mechanisms like wells and springs.

[3] GEC: Groundwater Estimation Committee

poor water quality in some areas. As more information becomes available, the number of broad categories may also increase, e.g. mountain systems can be further classified using the rock-type categories, but at this moment, there is little hydrogeological information from large parts of the region to attempt such a classification.

Figure 1: Generalised hydrogeological settings along with State and District boundaries (*developed from GSI, 1993; CGWB, 2005; COMMAN, 2005*) – developed by ACWADAM, Pune



The initial thrust of irrigation by tubewells following the Green Revolution was restricted to India's 30% alluvial areas (setting 1), which are generally characterized by relatively more pervious geological strata. But from the 1980s, drilling was extended to hard rock regions (in the form of 'bore wells') where the groundwater flow regimes are extremely complex. Deeper aquifers, where groundwater is usually under confined conditions, often have good initial yields, but a tube well /

bore well drilled here may be tapping groundwater accumulated over a longer period of time, often over several hundreds of years. Once groundwater is pumped from a deeper aquifer, its replenishment depends upon the inflow from the shallow system or from the surface, several 1000s of metres above it. Groundwater recharge in such systems proceeds slowly. This poses a severe limit to expansion of tube well technology in areas underlain by these strata. Similarly in the mountain systems (setting 3 in Table 2), which comprise 17% of India's land area, effects of groundwater overuse do not take very long to appear.

As the processes of groundwater accumulation and movement are vastly different in different geological types, the implications of any stage of groundwater development will vary significantly across types of geological settings. For instance, groundwater overexploitation will result in water scarcity much sooner in mountain systems than in alluvial systems. However, it is more likely that groundwater quality issues will emerge, parallel to groundwater exploitation in alluvial systems, issues that take longer periods and higher costs to remediate. Scarcity may not be a big issue over the short term in alluvial systems, but in volcanic systems, scarcity aberrations to water supply will be frequent and sensitive to changes in rainfall vagaries.

Table 2: Hydrogeological setting – Details of Areas and Distribution (States)

Hydrogeological setting	**Area (km^2)**	**States**	**Percentage of total area**
Mountain Systems	525067.107	Arunachal Pradesh, Assam, Haryana, Himachal Pradesh, Jammu & Kashmir, Manipur, Meghalaya, Mizoram, Rajasthan, Sikkim, Uttar Pradesh, Uttarakhand, West Bengal, Nagaland *(Total: 14 States)*	16%
Alluvial (Unconsolidated) Systems	931832.5	Arunachal Pradesh, Assam, Bihar, Delhi, Diu & Daman, Gujarat, Haryana, Himachal Pradesh,	28%
Sedimentary (Soft) Systems	85436.2341	Andhra Pradesh, Chattisgarh, Gujarat, Madhya Pradesh, Maharashtra, Orissa, Jharkhand, West Bengal *(Total: 8 States)*	3%
Sedimentary (Hard) Systems	194797.572	Andhra Pradesh, Bihar, Chattisgarh, Jharkhand, Karnataka, Madhya Pradesh, Orissa, Rajasthan, Uttar Pradesh *(Total: 9 States)*	6%

Sedimentary (Hard) Systems	194797.572	Andhra Pradesh, Bihar, Chattisgarh, Jharkhand, Karnataka, Madhya Pradesh, Orissa, Rajasthan, Uttar Pradesh *(Total: 9 States)*	6%
Volcanic Systems	525035.867	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	1023639.2	Andhra Pradesh, Bihar, Chattisgarh, Goa, Gujarat, Haryana, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Pondicherry, Rajasthan, Tamil Nadu, Uttar Pradesh, West Bengal *(Total: 17 States)*	31%

Figure 1 and Table 2 help us draw some important inferences. These are listed below:

- In a large number of Indian States, the hydrogeological setting is diverse. Diversity leads to complexity, hence in such complex settings, it is difficult to realize the implication of groundwater overuse and contamination at an aggregated level – district / state.
- Each hydrogeological setting is part of many states, the alluvial and crystalline rocks settings together having nearly 60% of the share of total States.
- The degree of heterogeneity in hydrogeological conditions is high in the mountain, volcanic and crystalline settings (*conditions in groundwater accumulation and movement change even over short distances*). The current estimation of groundwater use, viz. block/taluka/mandal is too gross to consider the question of heterogeneity or variability.

UNDERSTANDING GROUNDWATER – *CHOICE OF SCALE, TYPOLOGIES AND UNIT-BOUNDARIES*

A closer look at hydrogeological settings from across different parts of India has revealed that aquifers behave in various ways, especially in context to how much groundwater they store and the manner in which they transmit it. Aquifers respond to various fluxes – natural and anthropogenic – in many different ways. A combination of disciplines provides the first step in understanding a "typology" of groundwater resources (Kulkarni et al, 2009b). These disciplines include sociology, economics, engineering, ecology and others; however, hydrogeology provides the basis for the basic understanding on groundwater resources. A typology-based understanding makes it easy to develop strategies of groundwater management, relevant to the hydrogeological conditions, the status of groundwater use, the anthropogenic characteristics of the area and other such factors that have a significant bearing on groundwater use. The typology of groundwater in a region is especially important because it not only captures spatial variability arising because of specific hydrogeology, social-economic factors and even responses to problems. At the same time, a typology must also capture the 'time-dimension' over which transitions occur. South Asia's groundwater history, for instance has risen and fallen through 4 clear stages of a groundwater socio-ecology (Shah, 2009).

Groundwater typologies are particularly important not only in understanding problems but also in building appropriate responses to the problem. It is equally important to comprehend the issue of scale when dealing with groundwater typologies. Let us, for the purpose of understanding, look at the classical unit of groundwater assessment in India – a block/taluka/mandal. Figure 2 illustrates the meaning of typology, with the intention of understanding the 'groundwater situation' in a classical *unit* of assessment, say a block or a large watershed of say tens of thousands hectares. Let us, for the sake of example, consider that this unit falls under the 'overexploited' category as per the GEC[3] assessment. In such a case, the State Government, through the appropriate Department, is likely to impose certain sanctions, such as electricity regulation to curb further groundwater exploitation in such a unit. Based on detailed investigations, using hydrogeology, social mapping and other such surveys, the disaggregated picture of the unit can be broken down into three 'situations'.

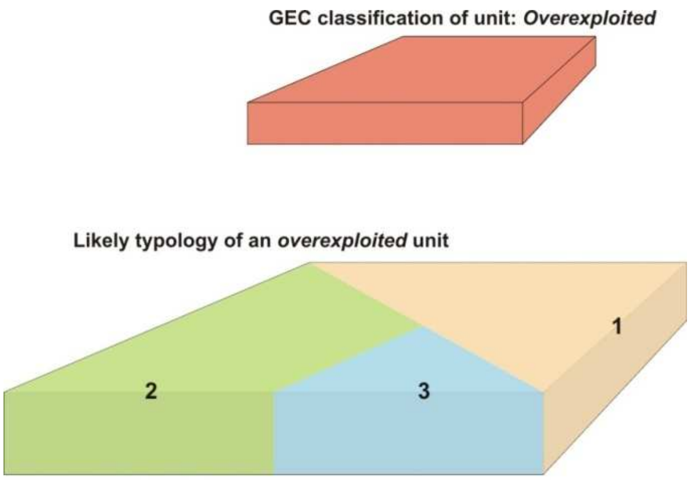
a. Area where aquifers show clear evidences of *overexploitation* – henceforth called 'overexploited type'.

b. Area where aquifers are not overexploited, but where some aquifer(s) show(s) problems of *groundwater salinity* – henceforth called 'groundwater salinity type'.

c. Area where groundwater resources are not developed or where *groundwater use is limited* – henceforth called 'limited groundwater-use type'.

ACWADAM has studied and analysed such a typology of aquifers and aquifer conditions, in detail, at least at two locations (Badarayani et al, 2008; ACWADAM, 2009b). In the first case, in Purandar taluka of Pune district in Maharashtra, three 'types' of groundwater-related issues were identified over some 15 villages (ACWADAM, 2009b). In the second instance, six different sets of conditions formed the typology of groundwater resources in parts of the Bagli tehsil of Dewas district in M.P. (ACWADAM-SPS Project – ongoing); this area is spread over some 600 km^2 and includes nearly 100 villages. Using a conventional aggregated picture, in this case, villages in the *limited groundwater-use type (no. 3 in diagram)* will tend to further fall back as any groundwater resource development is hindered because of regulations imposed under the current methodology of assessment. More significant, however, is the fact that a single unit of assessment has <u>three</u> sets of problems, requiring <u>three different approaches</u> of groundwater management (Kulkarni et al, 2009b).

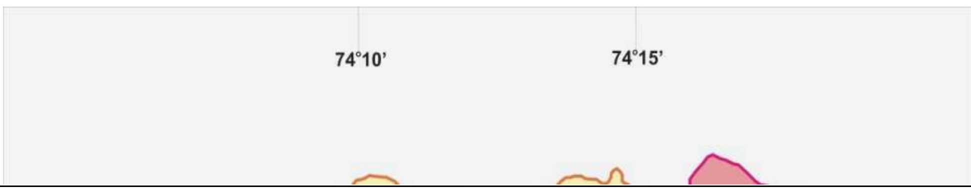
Figure 2: The Groundwater Typology of an Overexploited Unit

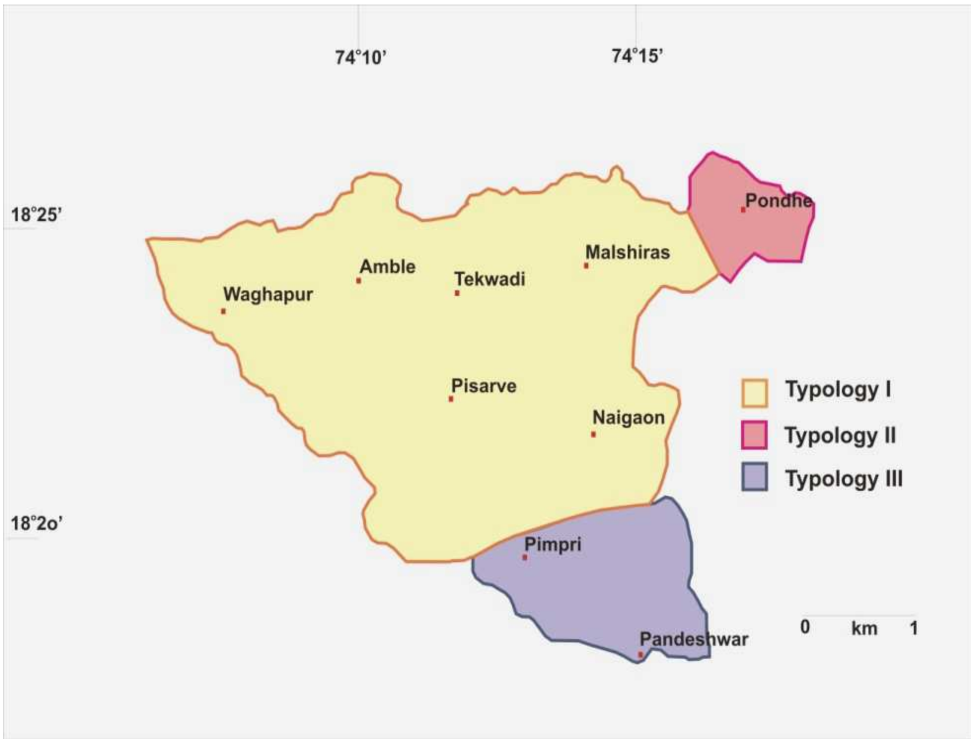


TYPE	AQUIFERS	PROBLEM
1.	Multiple	Groundwater overexploitation
2.	Multiple	Groundwater quality

There is great potential in using a *disaggregated* picture to analyse groundwater problems. A disaggregated picture has two clear advantages over an aggregated picture. The conceptualization of groundwater problems is clearer through a the disaggregated picture; this makes development of responses not only appropriate but also offers an opportunity to develop a feasibility analysis of what will be “acceptable” to the community, rendering implementation of responses under a “commons” philosophy, feasible. The next step is *piloting* some of these responses and gaining confidence on the ground. The piloting of responses for three different kinds of groundwater problems can be quite variable and therefore, prove to be challenging. Table 2 illustrates a menu of feasible responses under each of the three types, responses based on *hydrogeological and socio-economic characteristics* of the typology. The spatial representation of this typology is mapped in Figure 3.

Figure 3: Groundwater typology of a region (with some villages) (after Badarayani et al, 2009)





A detailed account of the hydro-socio-ecological typology of an area or region is useful in deciding the fit between watersheds, aquifers and the administrative units used to map, administer and govern groundwater users. As a case to illustrate this point, typology 1 indicates villages and watersheds within which aquifers have been overexploited – long term depletion of storage – because of progressive increase in abstraction in comparison to groundwater recharge. In typology 2, on the other hand, groundwater depletion is not apparent but groundwater salinity is the central issue. In typology 3, groundwater resources development is limited and so is groundwater usage, probably because of lack of electricity for pumping. Table 3 shows the relationship between watersheds, villages and aquifers; the example is from an area underlain by Deccan basalt, where a layered system of differentially weathered and fractured lava flows gives rise to multiple aquifers (Deolankar, 1980; Kulkarni et al, 2000), sometimes with complex relationships across watersheds and underneath habitations. Disaggregating information and groundwater understanding becomes important in this regard.

Table 3: Relationship between watersheds, villages and aquifers for a drought-prone region underlain by basalt rock in Pune district, Maharashtra state

	Typology 1	**Typology 2**	**Typology 3**
Watersheds	Upper parts of 3 watersheds (Ambale-Waghapur, Tekawdi, Naigaon-Malshiras)	Lower parts of the 3 watersheds (from typology 1)	One separate watershed, with clear ridge-boundaries.
Villages	10	2	1
Aquifers	4	2	2

Managing groundwater in aquifers such as the case illustrated above requires a multiple set of protocols. Moreover, such a *menu of options* for managing groundwater, especially with a 'commons' perspective, requires 'rigour'. At various levels of stakeholder dialogue, these options of managing the resource get refined further, but the relevance of each option depends upon how each typology is characterised. Table 4 is just a *first-cut* set of strategies of converting protocols (set of good practices) into actions on the ground, through a participatory process (potential action). Implementing protocols under types 1 and 2 would require support and initiatives at a much higher level, perhaps even including a back up through a formal legislative framework; the magnitude of desirable interventions in these two typologies would mean larger investments in terms of human resources, institutions and time-frames. On the other hand, under type 3, enabling a comprehensive groundwater management pilot is easier, with a lesser degree of external 'legislative' support.

Table 4: Example of qualifying protocols in the typology approach (coloured boxes indicate potential participatory pilots through a commons perspective)

Menu of groundwater management protocols	**Type 1**	**Type 2**	**Type 3**
Geohydrological science in Watershed Programmes (special reference to recharge and recharge area demarcation)	Relevant, with specific ' recharge' strategy for augmenting resource	Relevant with regard to groundwater salinity reduction	Not relevant
Recharge area protection (Forest cover & community lands) – as a special groundwater protection zone	Highly relevant, if recharge areas part of common lands and forest lands	Not too relevant if areas are part of agricultural lands	Relevant especially when linked to collective efforts of groundwater management
Efficient use of individual wells	Of secondary relevance because of large numbers	Relevant, but needs further probing of the groundwater salinity distribution	Highly relevant, especially with regard to community wells.

Pump capacity regulation	Highly relevant, but very challenging	Of secondary relevance	Not relevant under collective effort
Regulation of distance between wells (Drinking well protection)	Highly relevant but challenging (especially in the absence of formal legislation)	Highly relevant, only after restoration of water quality in the aquifer (may take years)	Not relevant in case of efficient execution of community based system
Regulation of agricultural water requirement (crop water requirement)	Highly relevant, but challenging	Relevant	Relevant (built into the community based groundwater system)
Groundwater sharing through community participation	Relevant, but extremely challenging – would need external support (policy, legislation, incentives etc.)	Not necessary in the current context	Relevant (built into the community based groundwater system)
Community sensitization and awareness generation for groundwater use	Relevant	Relevant	Relevant
Formal legislation	Highly Relevant	Relevant, but could not be as stringent as in type 1	Not necessary, especially if social regulation important

GROUNDWATER MANAGEMENT IN INDIA: *A "HORSES FOR COURSES" APPROACH*

Broadly speaking, the problem of groundwater overexploitation in India has evoked two kinds of responses, often polarizing the debate around the strategy for managing a resource that is not only diverse, but is highly situation-specific. The State and the formal governance structure keeps pushing for legislation while the Civil Society continues for community-based action and social fencing. In fact, many States in India are pushing forward for legislation, often in the form of Groundwater Acts and Water Regulatory Authorities (Planning Commission, 2007). Such legislation is clearly of the *command and control type* keeping in view areas where groundwater overexploitation occurs. The biggest drawback with regard to such legislation has been the degree of implementation, even in the case of protecting drinking water sources, primarily because of the generic nature of the legal provisions. Second, the advocacy on *community managed groundwater systems*, wherein groundwater use is regulated through norms of the *social-fencing* *type* continues, mainly through Civil Society initiatives. Having said that, *community efforts* at regulating groundwater demand have been few-and-far-between, although there is emerging evidence that such efforts are on in many different locations across India in the past decade or so (the APFAMGS Project in Andhra Pradesh and the Hivre Bazar example in Maharashtra are oft-cited examples). The COMMAN study in India (COMMAN, 2005) listed and discussed the limitations on collective action around groundwater resources as well as the limitations on implementing *command and control* measures. In its final findings, the COMMAN study (2005) identified the question of *scale* and the related *issue of exclusion* as the central challenges in community action on groundwater management.

Interestingly, both responses attempt to manage supply and demand, in a bid to protect the endangered resource, eventually. However, in actual terms, both these instruments have resulted in a common set of actions on the ground, actions that have heavily constituted *augmenting supply* by promotion of *increased recharge*. On the demand side, most efforts have attempted to regulate pumping through water-efficient application to crops, mainly using *drips and sprinklers* as water application technologies. Demand management, at the resource level (aquifers) remains a mirage of sorts. Overcoming the hurdles in the above two types of responses implies developing synergies between these two contrasting philosophies (often perceived at loggerheads by people who advocate them). Hence, as Kulkarni and Vijay Shankar (2009) state: “first, we need to support and empower community based systems of decision making; legal framework and groundwater management institutions ought to facilitate and enable community action”.

The responses to groundwater quality in India have largely been in the form of “firefighting”, as against the somewhat *overarching* responses on groundwater exploitation. Provision of alternative sources of drinking water poses challenges in developing short-term responses leading to “technological” fixes or hardware to “treat” contaminated groundwater. Some common factors that run across current responses in water quality treatment are summarized by Kulkarni et al (2009a) as follows:

- The nature of quality problems – Salinity, Fluoride, Biological (pathogenic), Arsenic, Iron – and their <u>possible combinations</u> require a wide variety of technologies of water treatment. This is more so in the countless situations driven by various *combinations of hydrogeological settings, sociological and economic conditions, the rural vs urban space and the nature of sectoral development (agriculture, drinking water and industrial environment across a region).* Emergence of newer problems such as increasing agrochemicals in drinking water makes the response arena more challenging. These complexities are seldom part of the current response strategy.
- Strategies of overcoming groundwater quality challenges have rightly used the approach of *habitations* as the viable units. However, within a single habitation, there are challenges to overcome. The variable affordability of households to water treatment technology within any village means that <u>not all</u> households are really capable or willing to pay equally for a commonly owned treatment system, especially since the best techniques of treatment such as Reverse Osmosis (RO) also come with costs that are outside the “saving capacities” of the rural poor. The challenge also lies in the fact that

capital costs are often through external funding but recurring costs (O & M) are presumed to be met from the 'user kitty'.

- The variable quality of water of *different sources at different times of the year* implies a customized approach involving proper treatment depending upon the source and the season. Current responses often consider the source, but seldom the seasonal dimension in groundwater quality.
- Adaptation of the technology to different needs in a highly intense cultural milieu is often difficult with constraints such as: i) many farmers drink water from wells in their fields, ii) single common source of drinking water for several villages also creates conflicts, iii) catering to old, disabled and remotely located inhabitants through a centralised technology is difficult.

Dealing with groundwater related problems clearly implies a set of actions including aquifers or groundwater systems. The spatial and temporal scales on which these systems operate, the overlap of the larger hydrologic systems with a groundwater system – watersheds and river basins – the scale and sizes of communities that depend upon groundwater, the uses of groundwater and questions of quality (geogenic and anthropogenic issues) are all equally important. Some of these relationships are discussed in the following section, with a view to begin unpacking the system of groundwater governance.

The package of the conventional responses suggested in context to the groundwater overdraft problem in India (Planning Commission, 2007; Shah, 2009) is as good a starting point as any in developing a strategy. The primary basis for such management, as mentioned earlier, must be *aquifers*. Each typology is a function of the hydrogeological setting, the stage (Shah, 2009) or level (GEC, 1997) of groundwater resource development, groundwater quality domain, health and the livelihood scenario. To understand this further, let us begin with a *national groundwater typology* including a broad strategy for ensuring drinking water security in different hydrogeological settings (Table 5). The table clearly indicates that even at the national level, the groundwater typology can be classified into three broad groups, based on the spatial and time scales on which processes occur – processes that include groundwater abstraction and quality changes, which themselves lead to profound impacts on society. It is interesting to note how clustering occurs (alluvial and soft sedimentary systems; crystallines and hard sedimentary systems; and volcanic and mountain systems). The 3 categories or clusters, for which some broad action points, including responses can be thought of, as follows:

1. **Alluvial (unconsolidated) and Sedimentary (soft) systems**:

- Aquifer-systems mapping at the scale of small river basins, in great detail, involving complex "groundwater modeling" tools.
- Comprehensive strategies of conservation and recharge.
- Mega-scale of groundwater management - small river basins (500-1000 km^2).
- Drinking water protection will have to involve strategies that cut across villages, e.g. cluster-level drinking water strategies.
- Regional protection zones, involving invoking robust instruments of

legislation.

- Time-frames for programme will also have to be longer, given that mitigation effects will take longer to be manifest in such systems.

2. Crystalline (basement) and Sedimentary (hard) systems

- Aquifer mapping at the scale of milli-watersheds.
- Strategies of conservation and recharge to be oriented to local dynamics of water availability and quality. Scale of groundwater management – milli-watersheds (100 km^2).
- Drinking water protocols need to be embedded within a larger groundwater management strategy, e.g. village-level drinking water protection as a part of the milli-watershed groundwater management strategy.
- Protection zones will be variable and complex and hence, will involve a combination of social and formal legislation.

3. Volcanic and Mountain Systems

- Aquifer mapping at the scale of micro-watersheds with emphasis on aquifer identification.
- Strategies of conservation and recharge to be oriented mainly towards rechage-discharge balances.
- Scale of groundwater management - aquifers (1 to 10 km^2).
- Drinking water protocol to be developed 'village-wise' e.g. protection zones will be of smaller magnitude and possible mainly through a social regulation, within a wider formal legislative net.

Table 5: India's groundwater variability and some strategic contours of evolving 'commons' based processes of groundwater management

Regional groundwater settings	Aquifers and boundary coherence	Groundwater recharge strategies and vulnerability aspects
Mountain systems	Highly localized aquifers but often with non-coherent village and aquifer boundaries	Local recharge systems, often outside village/watershed boundaries; depletion in natural discharge points, i.e. springs due to overexploitation through borewells; major groundwater quality impact being
Alluvial (unconsolidated) systems	Regional systems of multiple aquifers (an aquifer is overlain by many villages, also each village can vertically tap parts of multiple aquifers) – vertical boundaries between aquifers also important	Regional recharge systems with large-scale recharge; overexploitation trends involves successive depths of 'aquifer tapping' with exponentially rising costs of drilling and pumping; vulnerability of groundwater

	boundaries between aquifers also important	tapping' with exponentially rising costs of drilling and pumping; vulnerability of groundwater quality (geogenic and human-induced) not always linked to quantitative depletion
Sedimentary (soft) systems	Scales are variable – from local to regional aquifers – but not of the scale of alluvial systems (above); aquifers have somewhat regional connections and more than one village is likely to tap a common aquifer underneath	Local recharge, although magnitudes of recharge can be large; drinking water impacts on the groundwater quality tend to be more pronounced than on the quantitative side
Sedimentary (hard) systems	Localized occurrence of aquifers often with coherence between watershed and aquifer boundaries; usually one village-one aquifer	Local recharge systems, at places, outside village and watershed boundaries; depletion trends more on the quantitative side, with associated impacts on groundwater quality
Volcanic systems	Largely localized occurrence, often as multiple aquifers (vertical); watershed and aquifer boundaries often coherent but village may be underlain by many aquifers	Local recharge systems, at places, outside village and watershed boundaries; depletion trends more on the quantitative side, sometimes associated impacts on groundwater quality
Crystalline (basement) systems	Two types of situations – regional and local; complex relationships between shallow and deep aquifers; some aquifers with boundaries coherent with watersheds, others extending below more than one watershed; variable scale of one village – one aquifer to many villages – one aquifer	Variable systems of recharge – regional at places, local at others; depletion concurrently affects quantities and quality, making drinking water sources highly vulnerable

t_{exp}= Time of transition from "safe" to "overexploited" condition

CONCLUSION

The fugitive nature of the (groundwater) resource and the open-access domain in which it is commonly used, pose major challenges in implementation of CPR principles in the practice of groundwater management. At the same time, given the highly fragmented nature of groundwater access and keeping in mind the complex nature and diverse contextual regime of groundwater problems in India, a strategic approach to groundwater management is called for. Protecting and conserving a relatively small portion of the drinking water requirement in much of rural India almost clinches the case of using a 'commons' approach to managing groundwater. The diversity in primary conditions of the resource – aquifer storage, recharge and basic groundwater quality along with an equal amount of diversity and complexity in patterns of uses, compel the development of strategies to respond to groundwater over-use and deteriorating groundwater quality through a process-based approach, rather than big, one-fit-all prescriptions.

Managing groundwater as a ‘commons’ with regard to India’s groundwater situation would require specific actions on various fronts. The key elements of a strategic groundwater management plan are: **knowledge creation, supply and demand management, groundwater quality surveillance mechanisms, health surveillance, mitigation techniques communication, health-nutrition strategies** and **affordable water treatment technologies -** all of these suited to the highly diverse Indian context**.** The measures would require energizing local universities for research tuned to the problem, bringing civil society upto creating pilots, empowering the PRIs towards problem identification and mitigation and many such measures. In the domain of *new technologies,* there is great scope to involve industry, especially by providing further incentives for developing, deploying and maintaining such systems through the ‘Corporate Social Responsibility’ (CSR) initiative.

REFERENCES

Badarayani, U., Upasani, D., Dhawan, H. and Kulkarni, H. 2009. Hydrogeological studies for improved groundwater management strategies in the dryland areas underlain by Deccan basalts: an initiative in Purandar taluka. *ACWA Report H-09-1*.

Central Ground Water Board (CGWB). 2005. *Master plan for artificial recharge to groundwater in India*. New Delhi, Ministry of Water Resources.

Central Ground Water Board (CGWB). 2006. Dynamic Ground Water Resources of India (as on March, 2004). *CGWB Publ.*

COMMAN. 2005. Managing groundwater resources in rural India: the community and beyond. *British Geological Survey Commissioned Report CR/05/354.*

Deolankar, S.B. 1980. The Deccan basalts of Maharashtra, India - their potential as aquifers. *Ground Wat*., 195: 29–46.

DDWS. 2009. *Mid-term Appraisal of 11th Plan – Rural Water Supply*, mimeo, Department of Drinking Water Supply, Ministry of Water Resources, GoI, New Delhi.

Groundwater Resource Estimation Committee (GEC). 1997. Groundwater resource estimation methodology. *Report of the Groundwater Estimation Committee, Ministry of Water Resources, Government of India*.

Geological Survey of India. 1993. Geological Map of India. *Printed at Map Printing Division, GSI, Hyderabad*.

Kulkarni, H. (2005) Groundwater overdraft: a physical perspective. *In: COMMAN 2005. Community Management of Groundwater Resources in Rural India – Research Report, R. Calow and D. Macdonald (eds), British geological Survey Commissioned Report CR/05/36N., pp. 1-13.*

Kulkarni, H., Deolankar S. B., Lalwani A., Joseph B. and Pawar S. (2000) Hydrogeological framework of Deccan basalt ground water systems, India. *Hydrogeology Journal (Springer - Verlag), v. 8(4), pp. 368-378.*

Kulkarni, H. and Vijay Shankar, P. S. (2009) Groundwater: towards and aquifer management framework. *Commentary, Economic and Political Weekly, February 7, 2009.*

Kulkarni, H., P.S. Vijay Shankar and S. Krishnan (2009a): *Synopsis of Groundwater Resources in India: Status, Challenges and a New Framework for Responses*, Report submitted to the Planning Commission, Government of India, for the Mid-Term Appraisal of the 11th Plan (ACWA Report ACWA/PC/Rep-1).

Kulkarni, H., Badarayani, U., Upasani, D., Dhawan, H. and Gupta, R. (2009b) Understanding the typology of groundwater resources in India: key to building responses through communities. In (Eds: Kulkarni, H., Badarayani, U. and Upasani, D.) *Groundwater management – Typology of challenges, opportunities and approaches. ACWA H-09-2, Arghyam-ACWADAM Publ.*

Kulkarni, H., Vijay Shankar, P. S. and Krishnan, S. *in press* Groundwater governance: backing CPR principles with a process-based approach. *13th Biennial Conference of the International Association of the Study of the Commons, Hyderabad, India*.

Planning Commission, Government of India. 2007. Report of the Expert Group on Groundwater Management and Ownership. *Planning Commission, New Delhi. 61p.*

Shah, T. 2009. Taming the Anarchy: Groundwater Governance in South Asia. *Resources for the Future, Washington DC and International Water Management Institute, Colombo, 310p.*

http://www.cgwb.org