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Shaping the contours of groundwater governance in India

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ABSTRACT

Study region: India.
Study focus: India's groundwater dependence and the crises of depletion and contamination of groundwater resources require the development of a robust groundwater dependence framework. Understanding the challenges of developing a groundwater governance framework for regions of extensive groundwater development versus relatively less-developed areas of groundwater development is important. The groundwater typology is a function of both, the hydrogeological aspects of groundwater and the socio-economic milieu that defines dependency on the groundwater resource, which is significant across users and uses in India. An interdisciplinary perspective is important while managing groundwater resources in India and helping establish groundwater governance.
New hydrological insights for the region: Participatory forms of groundwater management, using 'aquifer-based, common pool resource' approaches have begun to find their way into the practices and policies dealing with groundwater in India. Participation at all levels is important in management decisions as well as in the development of a governance framework, knowing that groundwater development in India has been 'atomistic' in nature. Developing a regulatory framework that is supportive of 'protection' of the resource as well as 'good practices of participatory groundwater management' is essential in groundwater governance. Interdisciplinary 'science' must form the medium of promoting both groundwater management and governance instead of using it in the largely business-as-usual approach to groundwater resource management that remains 'infrastructure' based, 'supply-side'.

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1. Introduction

Innovative processes to produce food and provide for drinking water by millions of farmers from different parts of the world has been aptly labelled 'silent revolution' of groundwater development (Fornés et al., 2007; Llamas and Martinez-Santos, 2005). The trajectory of groundwater development in South Asia, labelled as 'atomistic' development by millions of farmers, is a clear example of this revolution (Shah, 2009). India is a groundwater-dependent nation. Even at conservative estimates, 85% of rural drinking water in India is derived from wells (The World Bank, 2010). With nearly 88% of the total annual groundwater drawn from all the wells in India being used for irrigation (IDFC Foundation, 2013), we estimate that nearly 700 million Indians who live in Indian villages, almost entirely depend upon groundwater for their daily needs. The growing demand from India's towns and cities and by the industry has meant increased groundwater use not only from within urban agglomerations, but also the export of water from adjoining villages (Janakrajan, 2008). Nearly 48% of the urban water share is derived from groundwater (Centre for Science and Environment, 2012).

Groundwater overexploitation maybe defined as a situation in which, for some years, average abstraction rate from aquifers is greater than or closer to the average recharge rate (Custodio, 2002). The national-level groundwater assessment in India that deals with estimates of groundwater use in proportion to annual replenishment of groundwater, has been made possible through a methodology developed initially by the Groundwater Resources Estimation Committee (Ministry of Water Resources, 1997) and revised later in (Ministry of Water Resources, 2009). Central Ground Water Board (CGWB), the apex national agency dealing with the national-level groundwater assessment indicates through these assessments how the area under groundwater depletion has increased since 1997 (Table 1). A comparison of the CGWB's assessments of 1995, 2004 and 2009 shows that the groundwater crisis has deepened until recently, although there appears to be a marginal improvement between 2004 and 2009 (Table 1).

However, the national groundwater assessment is indicative of the degree of groundwater usage when compared to the annual availability of groundwater resources. It does not include the dimension of groundwater quality. Indicative data drawn from various sources – (Krishnan, 2009; Kulkarni et al., 2009a,b; Central Ground Water Board, 2010; Vijay Shankar et al., 2011) – shows that groundwater contamination has emerged as a threat to drinking water security in many parts of the country. Groundwater exploitation and contamination have emerged across a diverse range of agro-climatic and hydrogeological conditions in India, with nearly 60% of the districts in India showing evidence of either depletion or contamination or both.

Even at a global level, socio-economic dependency on groundwater cuts across classical divisions of 'arid, semi-arid and humid' regions (Burke and Moench, 2000), highlighting the need to tailor responses to situations under which groundwater problems emerge. Moreover, the gap between society and science-technology is larger in the case of groundwater than surface water resources because of the relative 'newness' of intensive groundwater use (Llamas et al., 2006).

Three messages are highlighted under United Nations Educational Scientific and Cultural Organisation's (UNESCO's) global initiative on groundwater governance[3] summarising key messages from its global governance programme as:

- While groundwater use has increased manifold, with major socioeconomic benefits, little attention has been given to its governance and to resource conservation and protection.
- Rather widely, groundwater has in effect been abandoned to chance, intensifying extraction and increased pollution.
- Good groundwater governance is required to provide the right environment to facilitate sustainable management.

[3] http://www.groundwatergovernance.org/fileadmin/user_upload/groundwatergovernance/docs/general/GWG_updated_flyer_web.pdf.

Table 1
Comparative status of level of groundwater development in India – 1996, 2004 and 2009.

Level of groundwater development	Percentage of districts 1995	Percentage of districts 2004	Percentage of districts 2009
0–70% ("Safe")	92	71	73
70–90% ("Semi-Critical")	4	10	9
90–100% ("Critical")	1	4	3
>100% ("Overexploited")	4	15	14
Saline	–	0.5	1.2

Source: Central Ground Water Board (2006, 2011).

The combined impacts of an increasing demand and many 'layers' of supply even in a single village – tens to hundreds of wells, small dams and sometimes surface water systems like canals from large but distant reservoirs – have led to fundamental questions around the availability of freshwater resources in India (Kulkarni and Thakkar, 2012; Kulkarni and Shah, 2013; Shah, 2013). With at least 85% of the rural population depending upon groundwater for their daily drinking water needs and nearly 50% of the urban share of water supply being groundwater-based, drinking water security of nearly a billion Indians is at potential risk on account of India's groundwater crisis. Hence, while India grapples with managing its groundwater resources keeping in mind that millions depend upon this resource around which vulnerability to scarcity and contamination is on the rise, there is an increasing need to design a groundwater governance framework that is relevant to India's unique groundwater situation. This paper seeds basic ideas into a preliminary framework for groundwater governance in India, a framework that is likely to lead to more concrete policies, practices and institutions that will eventually form core elements of groundwater governance in India.

2. India's groundwater resources

The last half century has witnessed a spectacular development in groundwater use globally (Llamas, 2011), with an increase from 100 million m^3 in 1950 to 1000 million m^3 in 2000 (Shah et al., 2007). India's groundwater crisis is located within a *typology* that is as much defined by its physical setting as it is by the diverse set of socio-economic factors that drive the cause and are affected by the extent and nature of groundwater usage. The relationship between groundwater abstraction and recharge depends upon the "aquifers" which are tapped by an estimated 30 million wells, tube wells and bore wells; and, in many cases, which supply water to more than a million springs in the Himalayan region alone. The fundamental basis for good groundwater management is a clear understanding of aquifers, a statement of purpose that has now found its way into the 12th Five Year Plan (Planning Commission, 2012). India's groundwater typology is based on six broad hydrogeological settings (Kulkarni, 2005; Kulkarni et al., 2000). Even at an aggregated level, it is interesting to look at the relationship between broad hydrogeological settings (representing aquifer systems) across India, especially in relation to the administrative units, i.e. states and districts (Table 2). It is clear from the table that most of the larger states in India have mixed hydrogeological settings, prompting the question as to how the two main regions experiencing heavy groundwater exploitation, the northwestern region forming part of the Indo-Gangetic river basins and the southeastern region forming part of the Krishna-Godavari river basins compare with each other. The northwestern groundwater exploitation cluster encompassing the States of Punjab, Haryana, Uttar Pradesh, Rajasthan and Gujarat are underlain by thick and extensive unconsolidated sediments of alluvial origin while the southeastern groundwater exploitation cluster encompassing large parts of Andhra Pradesh, Karnataka and Tamil Nadu are underlain by crystalline rocks of igneous and metamorphic origin.

2.1. *Typology of aquifer setting*

India is a geodiverse nation, the consequences of which are evident in a widely ranging set of hydrogeological conditions across the country. This, in turn, has also given rise to different impacts of groundwater use and emergent groundwater contamination issues. Table 2 shows a broad distribution

Table 2
Hydrogeological setting – details of areas and distribution (states).

Hydrogeological setting	Number of states and union territories where present	Percentage of total area	Socio-economic context
Mountain systems: Local aquifers found over a large region that feed springs and streams, mainly in the Himalayan region; aquifers often fed by recharge from distant locations.	15	16%	Dependency for drinking water larger on springs and spring-fed streams than on wells; land-use change and climate are factors of immediate concern around resource sensitivity; agriculture largely rain-fed and dependent in some areas on a mix of surface water and groundwater
Alluvial (unconsolidated) systems: Unconsolidated river and Aeolian sediments deposited in vast plains; – largely within the Indus and Ganga river basins; multiple regional 'aquifers' that are thick and extensive – regional aquifer systems over large regions; accumulation and movement of groundwater is basically a function of the particle characters (size, shape, etc.) of the sediments.	25	28%	Large dependency of domestic water on groundwater resources; enormous use of groundwater for irrigation in many regions of the western (Indo-Gangetic) system and in the peninsular east coast (deltaic) region; eastern portions of the Ganga basin show limited usage in agriculture; groundwater quality across this setting is a major concern with Arsenic dominating many areas; heavy-duty extraction mechanisms and high energy costs dominate in Western parts of the Indo-Gangetic system; complex groundwater markets emerging in both the drier western parts of the basin as well as in the eastern (flood-prone) region in the form of 'collusive opportunism' (after Shah, 2009)
Sedimentary (soft) systems: Sedimentary rocks that have largely preserved their sedimentary status; i.e. rocks that have not undergone 'hardening' due to processes like diagenesis and low-grade metamorphism; aquifers regional aquifers over smaller regions	11	3%	Largely part of Central Indian Drylands; strong coherence with forests, mining areas and tribal dominant regions; most of these areas have large dependency on groundwater for domestic usage; many areas also interface with hard-rock terrains that show competition between soft-sedimentary aquifers and hard-rock aquifer often with competition for high yielding water, e.g. Malwa region in Madhya Pradesh; agriculture is largely dependent on groundwater where it is emerging more recently
Sedimentary (hard) systems: Sedimentary rocks that have undergone 'hardening' on account of various processes including 'low-grade' metamorphism; local aquifers over smaller regions with aquifer behaviour similar to hard-rocks of volcanic or crystalline origin;	11	6%	Mainly found in Central Indian drylands again with strong coherence with forests, mining areas and tribal dominant regions; most of these areas have large dependency on groundwater for domestic usage; the interface with hard-rock regions not as stark in competition as in the case of soft-sedimentary aquifers, e.g. Cuddapah region in Andhra Pradesh; agriculture is largely dependent on groundwater with some areas showing significant magnitude of groundwater extraction

Table 2 (*Continued*)

Hydrogeological setting	Number of states and union territories where present	Percentage of total area	Socio-economic context
Volcanic systems: Rocks like basalt, which have formed on account of eruption of lavas onto the surface of the earth; local heterogeneous aquifers over large regions;	13	16%	Most heterogeneous of all the aquifer systems; layered system of aquifers implies more vertical interference that often extends beyond aquifer and village boundaries; the limited amounts of storage in these aquifers often leads to some degree of self-regulating storages, although longer term declines are evident leading to constrained agricultural growth; conjunctive use prevalent in western portions which house the 'dam-dominant' region of India; largely inert nature of basalt implies relatively better groundwater quality compared to most of the other aquifer systems
Crystalline (basement) systems: Ancient igneous and metamorphic rocks, formed from the cooling of magma and by the processes of metamorphism (effect of temperature, pressure and burial); local to sub-regional aquifers over large regions;	19	31%	High dependency on groundwater for both drinking water and agricultural purposes; inhomogeneous aquifer systems; various degrees of groundwater extraction with intense competition around depth of wells and bore wells; Fluoride as a major groundwater contaminant; some areas showing clear evidence of 'exit' (as described by Shah, 2009) from agriculture; groundwater markets largely around rural to urban groundwater transfers

of the seven hydrogeological settings used to describe India's groundwater typology. As more information becomes available, the number of broad categories may also increase, e.g. mountain systems could be further classified using the rock-type categories, but at the moment, there is little hydrogeological information from large parts of the region to attempt such classification, the groundwater assessment also hinting at the Himalayan Region as being a "no-data" zone, in various groundwater assessments, leaving out millions of people living in habitations that almost entirely depend on aquifers feeding of springs in the Himalayan region alone, not to mention the Western Ghats – that run parallel almost to the entire west coast of India, the Eastern Ghats – that run parallel to nearly the entire east coast of India and other smaller mountain ranges present at smaller scales in the country.

Various degrees of exploitation are not necessarily restricted to any particular setting, but are evident across nearly all the hydrogeological settings of India (Fig. 1). The units of overexploitation (as identified in Central Ground Water Board, 2006) have been mapped on top of the hydrogeological settings – as differently shaded polygons representing 'blocks or talukas or mandals', the sub-district administrative units in India. The figure brings out an important conclusion *that even a single overexploited polygon is likely to be underlain either by one or more hydrogeological settings.*

Complexity and variability characterizes water management problems in general and even more so in the case of groundwater (Llamas and Garrido, 2006). As the processes of groundwater accumulation and movement are vastly different in different geological types, the implications of any stage of groundwater development, as projected under the current methodology of assessment, will vary significantly across types of geological settings. Clearly, therefore, we cannot have the same classification of the Level of Development for settings 1–2, on the one hand and settings 3–6, on the other. Thus, a much lower level of groundwater development in settings 3–6 (71% of India's land area) could be as "unsafe" as a comparatively higher level in settings 1 and 2. Thus, we need to exercise far greater caution in settings 3–6 as soon as the level of GD crosses 50%. Such a "categorical" assessment is important, particularly in the improvement of drinking water management strategies in India. Hence, while current national and state level assessments are indicative of the degree of groundwater abstraction compared to annual recharge, this assessment may indicate an exaggeration of the problem in some

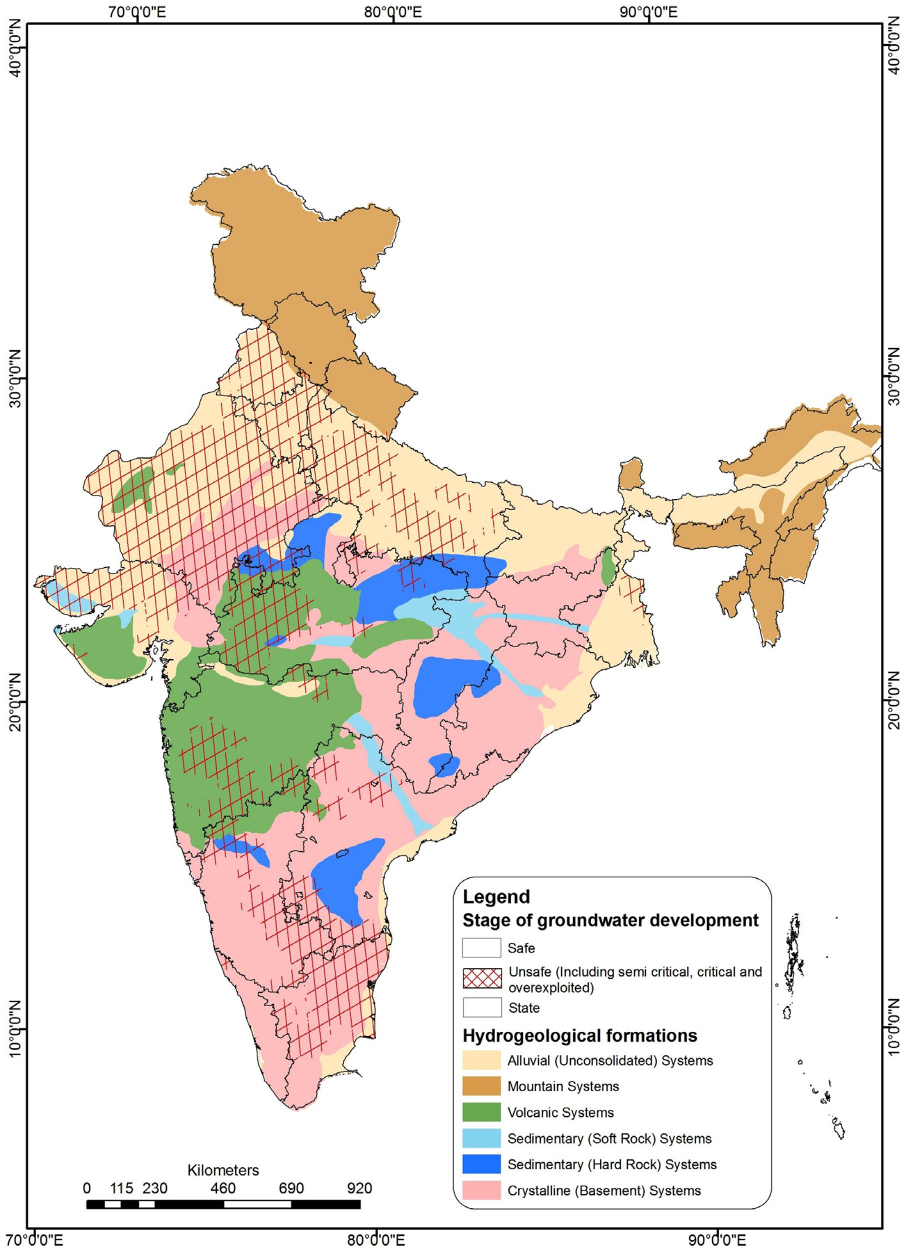

Fig. 1. Overlay of 'Unsafe' (*overexploited*, *critical* and *semi-critical*) blocks onto the Typology of Hydrogeological Settings in India. Modified after Kulkarni (2005) and Central Ground Water Board (2011).

regions while underplaying critical issues and underlying vulnerabilities in others. At the same time, an exaggerated statement of the problem may become actually serious if the 'colossal chaos' that exists in groundwater development is not addressed (Deb Roy and Shah, 2003).

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

- The hydrogeological setting is diverse in a large number of Indian States. Diversity leads to complexity. Hence in such complex settings, it is difficult to realize the implication of what “safe” and “unsafe – semi critical/critical/overexploited” really imply, especially when responses to problems like groundwater overuse need to be developed.
- Each hydrogeological setting is inclusive of many states, the alluvial and crystalline rocks settings together having more than 50% share. This aspect highlights the importance of understanding not only the hydrogeological nuances across different hydrogeological settings, but also the social and economic implications arising out of the different levels of groundwater use under each of these settings.
- The degree of heterogeneity in hydrogeological conditions (*conditions in groundwater accumulation and movement change even over short distances*) is bound to be high in many States, strengthening the case for a greater disaggregation of data for understanding groundwater exploitation and contamination. One of the more important implications of understanding such heterogeneity is the possibility of moving away from a one-fit-all water governance paradigm that is often articulated as the best way forward in tackling a set of groundwater management problems.

2.2. Groundwater exploitation and contamination: patterns across the typology

Groundwater use in India has led to multiple impacts, the most obvious being *fall in water levels* and *reduced well-yields*. With users having to pump water from greater depths, *costs* of deepening and drilling have been further compounded by the need to install *high-capacity pump-sets*. In many areas, this has also led to a continuous competition between users, leaving the poorer and marginalized behind in such a race, at the same time constantly increasing the burden of energy-subsidies per unit of pumped water to the exchequer. So, Indian policy makers have to tease out solutions from existing experiences in India, in the case of electricity from Gujarat's *Jyotirgram Programme* and West Bengal's experience (Mukherji et al., 2012).

The heterogeneous character of the resource, especially in the case of groundwater in hard-rocks (Kulkarni and Thakkar, 2012) and in the mountain systems, implies an inequity of endowment to different users (especially farmers) even in a typical village. Groundwater overuse further increases such inequity between users; it also creates competition between types of uses, mainly between drinking water and irrigation (Macdonald et al., 1995). Water conflicts are becoming endemic at all levels in India (Briscoe and Malik, 2006) with various social, economic and ecological dimensions to these conflicts (Joy et al., 2008). Much of the discussion around groundwater competition and conflicts is about impacts on groundwater level and quality. However, it is important to note that impacts on society, economy and environment are likely to vary according to variations in the hydrogeological settings as well as due to the variable socio-economic conditions pervading a region at any given point in time. The impact of a water level decline of 10 m in a crystalline rock aquifer is quite different from a similar decline in an alluvial aquifer. The time-frames over which such a decline occurs in these two types of hydrogeological settings, for a constant volume pumped, would be quite different. On the other hand, for a given decline in the water level in these two types, the volumes that are pumped out of the alluvial aquifer are bound to be greater than those from crystalline rock aquifers, at least by two orders of magnitude.

While it is important to understand the role of groundwater, especially in the economic value of its use in irrigated agriculture, it is equally important to acknowledge externalities of its economic uses, particularly in the form of agricultural diffuse pollution and impact of water management decisions on the environment (Llamas et al., 2012). Overexploitation has catalyzed the emergence of large-scale groundwater quality problems leading to potential threats to the health of large populations whose domestic water-security is endangered, given the large dependence on groundwater, particularly of the rural population. Salinity ingress in coastal regions and reduced river flows are also significant impacts resulting from groundwater overexploitation in many parts of the world, including India (Burke and Moench, 2000; Zaporozec, 2002; Foster and Chilton, 2003). Geogenic groundwater contamination has emerged as one of the fallouts of groundwater overexploitation in India.

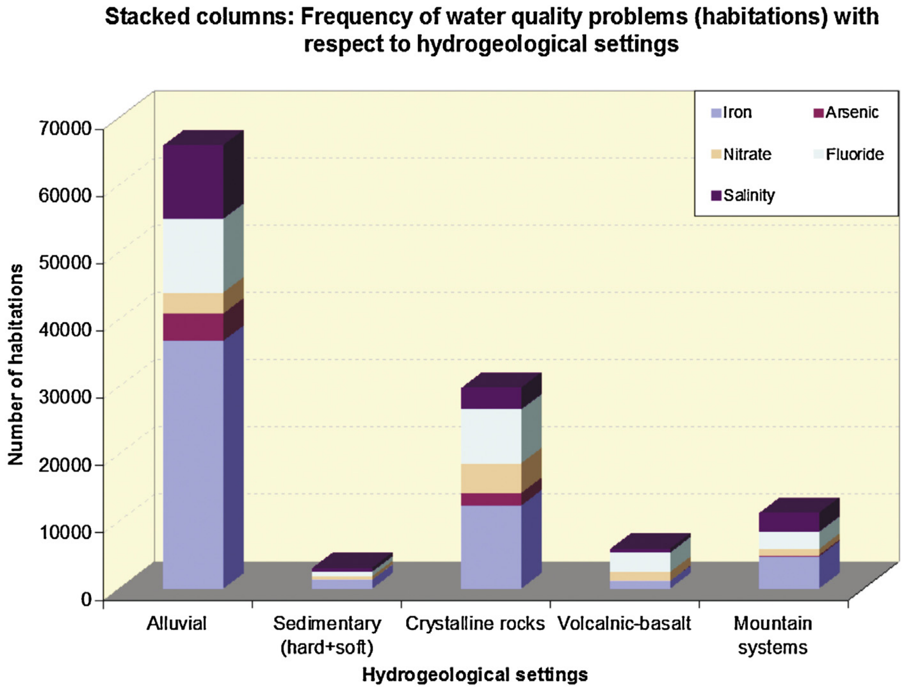

Fig. 2. Water quality problem (represented by frequency of affected habitations) in different hydrogeological settings.

The Department of Drinking Water Supply and Sanitation – DDWS (Department of Drinking Water Supply, 2009) estimates that as on 1st *April 2009*, there are still about *180,000 quality-affected rural habitations* in the country, nearly 27% of the total. According to the DDWS, out of 593 districts from which data is available, we have problems from high Fluoride in 203 districts, Iron in 206 districts, Salinity in 137 districts, Nitrate in 109 districts and Arsenic in 35 districts (Department of Drinking Water Supply, 2006). 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 trends are reported from other parts of the South Asian Region – as reported in other papers in this issue – especially with regard to Arsenic (Diwakar et al., 2015) and Fluoride (Hallet et al., 2015).

It needs also to be noted that just as with groundwater levels, issues of quality are also closely correlated with the nature of the hydrogeological setting. Using sample data some indication about the correlation between hydrogeological settings and poor quality-affected habitations can be established (Fig. 2). It is the alluvial regions that have the highest concentration of every kind of water quality problem in India, presenting us with a paradox of larger groundwater potential but with a greater vulnerability to groundwater contamination. It is quite likely that in alluvial regions, even at a comparatively lower level of groundwater development, quality degradation of a higher magnitude may set in earlier than it does in hard rock aquifers. So, while we must be very modest in the rate and depth of extraction of groundwater in hard rocks, the monitoring of groundwater quality and health in alluvial aquifers needs to be more rigorously carried out even at low levels of groundwater development. This is especially important in the light of policy initiatives to promote the level of groundwater development in alluvial Eastern India, where the present levels of use are relatively low.

Groundwater is considered to be less vulnerable than surface sources to climate fluctuations and can therefore help to stabilize 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), India being no different. As much as 70–90% of all water consumed on an annual basis is used for irrigated agriculture, globally (Llamas and Martinez-Santos, 2005). At the same time, groundwater also plays the important role of maintaining base flows in river systems. Each national groundwater assessment (Central Ground Water Board, 2006, 2011) indicates that nearly 34–35 billion cubic metres of water are naturally discharged by aquifers, as 'base flow' contribution to streams and rivers. Although this seems a mere 8% of the annual groundwater availability, it forms an important element of India's water resources. Given that much of the country receives rainfall over a period of 4–6 months, maintaining base flows in streams and rivers is of great significance, particularly in striking a balance between the development demands on groundwater resources for various purposes and its small but crucial role in contributing to environmental flows in river systems.

3. Groundwater governance: rationale for science, participation and legislative reform

India has reaped great benefits from its water infrastructure, which in turn has not been accompanied by improvement in governance of water resources and water services (Briscoe and Malik, 2006). The 'common pool' nature of groundwater has created a paradox of groundwater use and problems, particularly in India. While this has enabled a variety of people to access water for various purposes, often under various kinds of duress and hardship, groundwater access has focused on the creation of sources, increasingly running into resource-centric problems at scales of aquifers. Groundwater use in India is unique both in scale and characteristics of development, requiring management approaches that not only address the peculiar needs of groundwater settings but also need to adapt to the broader contexts of governance and the political economy (The World Bank, 2010). Some researchers argue that as long as the groundwater system is well understood in order to evaluate impact, there is no fundamental reason to think that temporary over-exploitation of aquifer storage for economic benefit is undesirable (Foster, 2000; Price, 2002). This rationale would be acceptable to most economic planners, and the case of tapping the so-called 'static aquifers' in States like Rajasthan (Planning Commission, 2007) is a typical example.

In practice, however, groundwater usage in agriculture tends to exhibit a competition on "who pumps out more and how quickly", either through deeper wells or larger pumps. With increasing industrial and urban water demands (Centre for Science and Environment, 2012), the arena of competition and conflict will only grow around a largely unseen, invisible and fugitive resource. The situation of electric supply in rural India only adds to such competition. In such a *race to the pump-house*, common pool resources are rapidly converted to private goods. Hence, as Foster and Chilton (Foster and Chilton, 2003) point out, groundwater resource degradation is "much more than a localized problem" and that it threatens the sustainability of the resource base, on a "wide-spread geographical basis". At the more regional scale, Shah (Shah, 2009) describes the need to include conjunctive management of surface and groundwater and addressing the water-energy nexus in developing groundwater governance in response to tackling groundwater anarchy while sustaining and improving South Asia's irrigation economy.

The re-emphasis of the shift in focus from a groundwater resource development agenda to a groundwater resource management programme is strengthened on how groundwater recharge and abstraction vary in proportion to each other as an aquifer depletes over a period of time (COMMAN, 2005). The consequences of groundwater depletion on the agrarian economy and groundwater markets occur through a four-stage socio-ecology of groundwater development (Shah, 2009). The diverse typology of groundwater settings and the complex nature of situations within which the groundwater crisis in India remains mired, require a diverse range of approaches and protocols for groundwater management. The 'protocols' of groundwater management (Planning Commission, 2007) include strategies of groundwater recharge and protection as part of watershed development, protection of natural recharge areas, efficient well-use, regulating energy (particularly pump capacities), determining the distance between wells and well-depths, crop water management (crop regulation and efficient application) and the possibility of well-user groups including markets. Enabling such protocols and integrating direct interventions in groundwater management with other programmes on natural resources make it imperative that India develops a framework on groundwater governance.

Groundwater governance is about decision-making on groundwater, involving individuals and/or organized entities at various levels (International Groundwater Resources Assessment Centre – IGRAC).[4] Groundwater governance comprises the promotion of responsible collective action to ensure socially sustainable utilization and effective protection of groundwater resources for the benefit of humankind and dependent ecosystems (Foster et al., 2010). The four broad tenets of groundwater governance are transparency, participation, information and the custom and rule of law (Saunier and Meganck, 2007). All of these are defined by efficient processes and must be supported by the 'art' of administrative action and decision making.

The biggest challenge in the development of a groundwater governance framework in India is the disconnect between the largely 'atomistic' development and pumping of groundwater through some 30 million access points across the country on one hand and a vaguely defined water governance system on the other. Adoption of an 'ecosystem' view in perceiving groundwater governance seems a good first step to integrate solutions towards a complex problem such as in the case of the Punjab Water Syndrome (Kulkarni and Shah, 2013). Aquifers are the ground for convergence of participatory mechanisms of groundwater management with an effective groundwater governance system. Monitoring, sound aquifer knowledge – poor knowledge implies wrong decisions including perverse subsidy – and calculation or modelling of aquifer behaviour are needed in the framework of a set of objectives and policies (Custodio, 2002). Hence, a balance between instruments of protecting aquifers and moderation of use of water from such aquifers could form the fundamental principle on which a groundwater governance frame can be developed.

3.1. *Groundwater governance framework*

The growing demand for irrigated food production in light of the great amount of usage of groundwater in the Indian sub-continent complicate the development of strategies for using groundwater resources sustainably, particularly with the additional dimension of climate change (Mukherjee et al., 2015). Further, the unique socio-ecological situation, including the diverse typology of groundwater resources, implies that groundwater governance in India must begin with major reforms in the policy and practice of groundwater, keeping the principles of equitable access and distribution, efficiency of usage and sustainability of resources in mind. Moreover, even a classical 'aquifer-based' approach has been missing in the development trajectory of groundwater, given the atomistic (Shah, 2009) nature of groundwater development driven by supply-oriented, technology-driven solutions. This is also the reason why standard aspects of governance – legislation and policy – have not worked in the favour of building a case for strong groundwater governance in India. Appropriate use and application of the following aspects that concern effective management of groundwater resources is important in the development and evolution of the groundwater governance framework in India:

1. Science
2. Participation
3. Regulation

3.1.1. *Science: aquifers as ground for participatory processes*

Groundwater is a *fugitive* (cannot be held "captive" underneath a defined piece of land) and *invisible* (as a subsoil resource it is largely unseen) common pool resource (Blomquist and Ostrom, 1985; Ostrom, 1990). 'Aquifers and aquifer-based participatory management' forms the cornerstone of reforms in groundwater management and governance in India. This approach, in turn, sets down the logic for institutions especially in the form of a set of rules, norms and values in the governance of groundwater as 'commons', further strengthening the case for a balanced development and ecosystem approach towards groundwater governance. Therefore, not only must the definition of the "science" under such a perspective be reviewed but also the scope of such science must go beyond locating sources for groundwater access and build a strong case for the management of the resource.

[4] http://www.un-igrac.org/dynamics/modules/SFIL0100/view.php?fil_Id=160.

For many, the science of groundwater may connote the subject of hydrogeology and well-water engineering alone. However, here the term science is used in context to understanding aquifers and their characteristics as well in developing efficient and equitable supplies and managing recharge through programmes like watershed development. Most importantly, an in-depth understanding of sociology and economics, often the drivers of demands imposed on a resource, are an equally important aspect of such a science, given the significance of managing groundwater demand whether it be a response to groundwater overuse or the impacts under a changing climate (Kulkarni and Thakkar, 2012). Hence, major improvements in the application of 'science', including the content and delivery of groundwater education curricula, will be important in groundwater governance, because data and information are not only part of science but are also an effective instrument of supporting decisions at different levels of groundwater management.

One of the pillars of good governance is accurate data and information (Zaporozec, 2002). Groundwater data in India has limited scope in decision support today because of the following reasons. It is important to pay attention to these factors while developing instruments of groundwater governance.

- *Data is indicative but not representative*: Most groundwater data collected by State and Central Agencies has evolved to a level of providing a regional perspective on groundwater use and groundwater quality. However, the current groundwater assessment is indicative of conditions within administrative units, not necessarily representing aquifer status or even groundwater conditions in watersheds. Moreover, data is not necessarily representative because disaggregated-level assessments indicate conditions otherwise (COMMAN, 2005; Kulkarni and Vijay Shankar, 2009). Although CGWB, the leading groundwater organization in India has put much of the centralized data in the public domain, not all information is easily accessible. The more local data and information collected by other Departments of the Government such as the Ministry of Drinking Water and Sanitation, Ministry of Agriculture and data collected by research organizations and Civil Society, as part of their development programmes, must find its way into public domain.
- *No system for decision support at appropriate scales*: India's diverse groundwater typology implies that aquifer scales vary over different orders of magnitude. In the absence of data at the right 'scales', both temporal and spatial, decisions on management of groundwater are often 'ad-hoc'. Lack of data and information at the appropriate scales often precludes decision support systems which otherwise exist in the form of village governance councils of watershed committees or drinking water and sanitation committees.
- The most common observation across India is the rampant free riding of a resource for which many useful conservation efforts are underway through flagship programmes of the government, whether in the form of Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), Integrated Watershed Management Programme (IWMP) and Drinking Water Pilots. Despite good work on the supply and supply augmentation side, the limited application of resource understanding (particularly aquifer characteristics) forecloses efforts on the demand side, leading to free riding on the benefits of conservation created through 'public' resources and programmes.

Implementing groundwater management and protection measures needs quantitative appraisal of aquifer evolution and effects based on detailed multidisciplinary studies supported by reliable data (Custodio, 2002). Hence, the purpose of collecting and using hydrogeological data and science has changed as a consequence of the changing paradigm of groundwater management. A change from exploring new sources of groundwater to a more resource-management objective implies improved data and information at appropriate scales, rendering improved decision support on aquifer-based, community-centric groundwater management.

3.1.2. Participation

The 'tragedy of commons' is a myth in water management with hundreds of documented case studies of local water users devising institutional arrangement to successfully govern their use of shared water resources (Schlager and Lopez-Gunn, 2006). This clearly implies that 'collective' groundwater management is not necessarily 'utopia' and therefore, quite challenging to implement, but that the lack of sustained mechanisms of governance preclude large-scale adoption of the concept. At the same time, lack of groundwater governance – particularly that of devising and maintaining institutional arrangements around groundwater (Schlager and Lopez-Gunn, 2006) – and the question of appropriate scales of setting up such institutions have been major blocks in converting open-access to groundwater to collective and even co-operative forms of managing this common pool resource. User participation is clearly important in co-operative management of groundwater resources. User participation requires a significant degree of trust among stakeholders, requiring transparent and widely available data (Llamas, 2011). Applying a scientific understanding to drive processes resulting in equitable, efficient and sustainable groundwater management requires strong "community participation". While research alludes to the importance of participation and its effectiveness in supply-side interventions such as managed aquifer recharge (Shah, 2009; Gale et al., 2006), participation remains crucial to groundwater demand management. Over the last few years innovative approaches across the country have shown light on how this paradox might be resolved (Table 3) and while there may be some merit in the argument of the degree of success in each of these stories, their common approach of dealing with groundwater supply and demand through multidisciplinary application of science, social science, economics and ecology sets them apart from a traditional 'supply-oriented, largely 'infrastructure-driven' approaches. Participation of different levels has been common to all these processes and participation remains the key to building institutions that can carry forward and sustain groundwater governance systems, especially at the scales of villages and small towns where it is needed most. Many, like the authors themselves, have been part of some of these efforts including the integration of reforms at both, the water management and water governance levels, under the 12th Five Year Plan.

While participation and participatory processes are important in developing a robust groundwater governance framework, external factors such as energy as an instrument to regulate groundwater use patterns (Shah, 2009) or crop choices to adjust to aquifer conditions and environmental fluxes (Kulkarni and Shah, 2013; Das and Burke, 2013) are equally important in regulating demand. Achieving effective management outcomes and sustaining them depends upon the wider environment of governance and the development and livelihood choices that environment generates (Moench et al., 2012). Hence, groundwater governance must encourage and combine regulatory instruments that integrate social norms, conventional legislation and major reform in the way regulation is envisaged here.

3.1.3. Regulation

Confusion over groundwater's legal ownership is a consequence of many factors, with the overall water situation in Spain still uncertain after 20 years since the 1985 Water Law (Fornés et al., 2007). While Indian States have taken steps in developing groundwater legislation as part of the larger water management agenda, the application of such legislation has remained limited (Cullet, 2014). Since the 1970s, the Government of India has put forward several model bills to regulate groundwater for adoption by the states. But these model bills only introduce a limited regulatory framework and amount to little more than "grandfathering" existing uses. What is remarkable is that some of the most important legal principles governing groundwater even today were laid down in British Common Law as early as the middle of the 19th century and have not been updated since. Existing rules of access to and control over groundwater are still based on the common law doctrine of absolute dominion, while large-scale groundwater usage has emerged in India only during the last 3–4 decades. Landowners do not own groundwater but enjoy access as part and parcel of their ownership rights to the land above.

When many users simultaneously pump groundwater, complex interference results between different foci of pumping, a common feature in many parts of India, where wells are located quite close to one another. Understanding such 'transience' is important and requires good understanding of aquifer size, specific storage and permeability (Custodio, 2002). In such situations, natural groundwater flow is altered and groundwater moves, depending upon the distribution of pumped water levels in different parts of the aquifer, again making it difficult to create rules based on defined streams of water akin to surface water movement. What is worse, the present legal framework only considers the interests of landowners, completely overlooking the hugely important fact that groundwater serves the basic needs of life of so many people who do not own land.

Table 3
Examples of groundwater management involving participation at village or village-cluster levels.

Organization(s) and location	Programme	Scale	Resource person(s)	Core strength	Tools used	Protocol
APFAMGS (Andhra Pradesh)	FAO supported	Villages across several districts	Farmers	Farmers record hydrologic variables	Simple budgeting tools in Excel and display of data	Crop water budgeting
PSI (Uttarakhand), ACT (Kachchh), ACWADAM (Maharashtra), WASSSAN (Andhra Pradesh)	Participatory Groundwater Management supported by Arghyam Trust, Bengaluru	Aquifer scales – local to regional	Rural communities	Aquifer-based groundwater management	Simple techniques of mapping and measurement of groundwater levels, quality, spring discharges and demand	Multiple protocols as appropriate
IWMI & partners' MARVI project (Rajasthan and Gujarat)	ACIAR	Villages/watersheds	Various levels	Co-creating knowledge on aquifer behaviour through local human resource capacity development	Groundwater level changes, groundwater quality	Socio-economic knowledge to catalyze community approaches to collective management of groundwater demand enhancing aquifer resilience
INREM Foundation (Gujarat & Madhya Pradesh)	SDTT	Villages	Community resource workers	Fluoride understanding and mitigation	Water quality testing and health-nutrition screening	Safer sources/filters and improved health and nutrition
Maharashtra	Hivare Bazar GP	Village/Watershed	Sarpanch – village chief functionary (Mr. Popat Pawar)	Rainfall based water budgeting and GP rules	Measurement and participatory tools	Rainfall, water levels, crops

APFAMGS: Andhra Pradesh Farmer Managed Groundwater Systems; PSI: People's Science Institute; ACT: Arid Communities and Technologies; ACWADAM: Advanced Center for Water Resources Development and Management; WASSAN: Watershed Support Services and Activities Network; IWMI: International Water Management Institute; INREM: Indian Natural Resource Economics and Management.

Social norms in regulating groundwater usage and ensuring security of groundwater resources holds the key in managing the highly decentralized and disaggregated nature of groundwater use in India. For one, social norms can be customized to a location and/or a situation. It often evolves through participatory processes that combine science, technology and influence social behaviour. Social norms require community acceptance and might appear to be challenging to begin with, but given some of the constitutional decentralization processes, *Gram Sabha* – special meetings of all adults in a village that provide oversight to gram panchayats or local governance bodies in Indian villages – resolutions are currently the strongest instrument of a legal ratification of such norms developed at community levels. However, experience suggests that despite good social norms and *Gram Sabha* ratification, there is no guarantee against some or the other form of free-riding in aquifers with regional extents, particularly in alluvial and sedimentary aquifer settings. This is where "regulatory and legislative processes" become important.

A command and control type of legislation is not only difficult to implement and scale-up, but also the conflict between decentralized and complex patterns of groundwater use and the centralized forms of groundwater legislation that States in India are empowered to develop and execute, makes any such legislation ineffective. However, if legislative reforms in groundwater law consider protecting participatory-social processes through instruments of law, it will enable a more 'legal' status to social processes. Hence, legislation and social processes can be complimentary to each other. Moreover, unless and until groundwater legislation includes protecting resources, including the environmental role that aquifers play, rather than the more direct sets of norms like depths of wells and distances between wells for different purposes, the purpose of groundwater governance would be partially served. Therefore, one must return to some tenets of conventional legislation albeit in a reformed version.

4. Groundwater management and governance: roles and processes

Complexity and variability are evident in the case of groundwater management problems and relate to scarcity of data, strong non-linearities in groundwater recharge, scientific knowledge and changing social preferences (Llamas and Garrido, 2006). Given the large degree of groundwater dependency across the country, we propose a framework of roles at different levels, using basic administrative units to embed the evolving institutional framework. The policy focus in such a governance framework will be around building capacities and facilitating regulation for protection with the purpose of ensuring sustainability or aquifers, equitability in access and distribution of groundwater, whether sourced from wells or available through springs. At the same time, groundwater access and usage will shift from a 'source-based' approach to an aquifer-based approach including recycling and reuse of groundwater and participatory recharge and demand-management processes. By doing so, the highest priority in groundwater governance will be accorded to ensuring and maintaining drinking water security in large areas of India's rural landscape. The central idea in moving to an aquifer-based framework is also to facilitate co-management of inter-sectoral water demand and supply from a single aquifer, a challenge that is already emerging in regions of transitions – agriculture to industry and rural to urban.

Enabling a balance between policy and practice (Fig. 3) requires focus at different levels of the administrative and governance structure in India (Fig. 4). These levels may be listed as:

- At point sources of use – villages (rural) or wards (urban) – aquifer mapping integrated with groundwater management piloting is proposed. This will be done through combining efforts on participatory groundwater management with mainstream programmes in agriculture, watershed development and livelihood and employment generation that already have certain institutional structures in place.
- The district units will be empowered to facilitate convergence between groundwater management and various programmes under implementation. Hence, *Gram Panchayats*, *Ward Sabhas*, *Watershed Committees*, *Drinking Water and Sanitation Committees*, etc. will be used to embed the principles and practices of groundwater management.

Fig. 3. Integrating policy and practice of groundwater management in India.

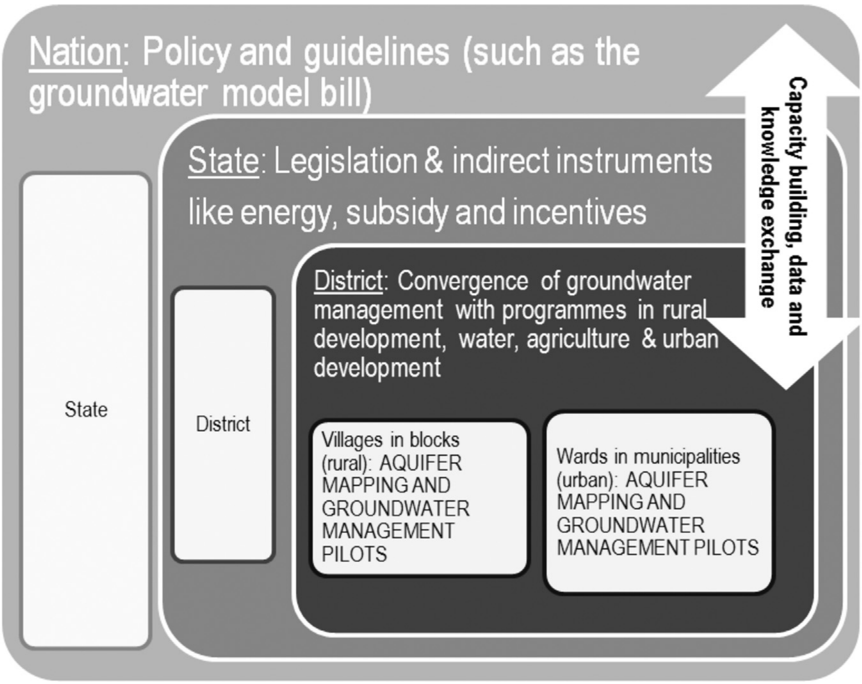

Fig. 4. District, state and national level initiatives for groundwater governance in India.

- States will be encouraged to strengthen their organizational capacities in aquifer-based groundwater management, primarily to regulate groundwater through a changed focus on legislation as described earlier and by encouraging indirect instruments of regulation, mainly energy reforms.
- Policy and guidelines will need to be sharpened, whether in terms of the nature of investments in flagship programmes of the Central Government like the Integrated Watershed Management Programme (IWMP) or the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGN-REGS) or in the form of including protection of certain key areas for groundwater recharge, conservation and ensuring a minimum contribution of base flows to streams and rivers.

Central and State Agencies dealing in groundwater have limitations in ensuring groundwater management at the levels of villages (decentralized administrative units) and aquifers (appropriate resource units) without appropriate application of science and participatory processes that include a stamp of governance. Hence, large-scale capacity building, data and knowledge on aquifers and aquifer-based management are required across the typology of groundwater resources in India. Demystification of knowledge, gathering of data at the appropriate scales and free-flow of data, information and capacities is strongly recommended as a means of connecting institutions at different levels.

5. Processes enabling groundwater governance

The (global) water governance initiative of Organisation for Economic Co-operation and Development (OECD)[5] highlights, through the constitution of its working groups, the importance of stakeholder engagement, governance of water services, basin governance and integrity and transparency. The way forward, though, has to evolve on the basis of sound science and strong socio-environmental skills in understanding the resource and developing community-action around its management also keeping a high degree of transparency in the process itself. While taking groundwater governance forward, we propose that India's planners focus on five key activities that integrate groundwater management and governance. Each has been listed below, in brief:

5.1. Capacity building

User participation requires a degree of hydrogeological education, still absent in many places in the world; such education must involve politicians, water decision makers, users and general public (Llamas, 2011). Unless assessed and considered within the basic 'aquifer framework' the understanding (at the right scale) of groundwater will continue to be fuzzy. Aquifers must also become the starting point for 'capacity building' at all levels – in the formal sector of education as well as in capacity building exercises for practitioners working under various programmes in rural and urban development. Capacity building must include understanding the problems (hydrogeological setting, stage of development, extent of water quality and the vulnerability to different stresses) in different types of aquifers and the menu of responses to deal with problems appropriately. Capacity building modules would need to be customized for different stakeholders, where each stakeholder is a *learner* and there are *no experts*. So, capacity building will need to be more in the 'workshop mode rather than a classroom mode', with the onus on 'aquifers, their mapping and their management'.

The main purpose of building capacities must be to demystify the science of groundwater in order to get across concepts of aquifers, common pool resources, equitable distribution, efficient usage and resources sustainability to a diverse set of stakeholders, who could be then turned into groundwater managers as part of the institution building process. Such demystification will pave the way for efficient collaborative processes leading to pilots on groundwater management, some of which are already shaping up in the form of as 'islands of success' than scaled out versions of management.

5.2. Collaboration

The basic factors that will govern the effectiveness of groundwater management are *a solid hydrogeological base, strategic social engineering and appropriate tools and technologies*. Social surveys, remote sensing, geophysics and GIS are techniques that can prove to be useful in groundwater management processes. *The need to integrate science, technology, sociology and economics is the fundamental rationale for collaborative processes*. Protecting rural livelihoods, especially in a country like India, and ensuring groundwater management at the same time, can be a challenging exercise. However, the sustainability of such livelihoods cannot be ensured without proper strategies on natural resource management, groundwater being one of them.

Given the diverse nature of the processes, it becomes important to involve multiple types of institutions/expertise in developing groundwater management plans for an area. Therefore, rather than specifying institutions, which would be the obvious way forward, the roles required to run the above

[5] http://www.oecd.org/gov/regional-policy/OECD-Initiative-Water-Governance-ToR.pdf.

processes are important. These roles (which also indicate the corresponding process) should broadly include:

- Aquifer mapping, groundwater characterization and modelling
- Social surveys and models of participation
- Developing the typology of resource conditions in a region
- Community dialogue and mobilization
- Conduct of key meetings like Gram Sabhas, wherein communities lay down some consensus on management of groundwater resources.
- Co-ordinating roles of formal agencies such as the State Groundwater Boards, Electricity Boards, Soil and Water Conservation Department, and Drinking Water and Sanitation Department.

5.3. Piloting

Groundwater-related challenges in India provide living laboratories for hydrogeologists, social scientists, economists and environmentalists to collaborate. A good collaborative process should lead to a concrete strategy of piloting such efforts, depending upon the typology of groundwater conditions in a region. The logic for such an approach is quite simple. The complex environment within which groundwater management can occur hinders the development of ideal models. The Pani Panchayats of Maharashtra, which remained a model for equitable distribution of surface and groundwater, but got eroded on account of free-riding by individual farmers, is a glaring example (COMMAN, 2005). Each pilot should have a provision for impact assessment, which could feed back into the improvement of the piloting process itself as well as in improving and scaling up response strategies. These lessons could also lead to the strengthening and evolution of a robust legal framework and refining policy through continuous inputs from developments on the ground.

5.4. Legislation

Given the fact that even if communities come together to develop social norms around groundwater resources, they are not necessarily outside the potential impact of 'free riding' of benefits of conservation of groundwater resources through various such norms. New developments in jurisprudence have created both the basis and the necessity to redefine the legal framework for groundwater. These include:

- new water law principles (for instance, the Public Trust Doctrine enunciated by the Supreme Court), which suggest that water, and groundwater specifically, should lie in public trust and that the State at all levels (from the panchayat to the state government) is the custodian of the resource
- environmental law principles (for instance, the precautionary principle)
- decentralization principles embodied in the 73rd and 74th amendments to the Constitution of India
- changes in irrigation law focusing on participatory irrigation management over the last 15 years and implemented in a number of states
- the fundamental right to water that has been a part of Indian law for the past two decades and
- protection principles, such as the prevention and precautionary principles, most recently statutorily recognized in the National Green Tribunal Act, 2010.

Keeping these in mind, the Twelfth Plan by Government of India has proposed a new Model Bill for the Protection, Conservation, Management and Regulation of Groundwater, all part of the larger Water Governance concept. It is based on the idea that while protection of groundwater is key to the long-term sustainability of the resource, this must be considered in a framework in which livelihoods and basic drinking water needs are of central importance. The overall objectives of the model bill are (Shah, 2013; Planning Commission, 2012):

1. to regulate iniquitous groundwater use and distribution to ensure that the safe and secure drinking water/domestic needs of every person and irrigation needs of small and marginal farmers can be met;
2. to regulate over-extraction of groundwater in order to ensure the sustainability of groundwater resources, equity of their use and distribution, and to ensure fulfilment of ecosystem needs;
3. promote and protect community-based, participatory mechanisms of groundwater management that are adapted to specific locations;
4. prevent and mitigate contamination of groundwater resources promote and protect good conservation, recharge and management practices;
5. protect areas of land that are crucial for sustainable management of groundwater and ensure that high groundwater consuming activities are not located in areas unable to support them.

5.5. *Policy*

The revised National Water Policy (Ministry of Water Resources, 2002) has three basic points pertaining to groundwater resources.

- The need to regulate exploitation of groundwater
- The need to integrate surface and ground waters through a conjunctive management
- The need to avoid overexploitation especially in the coastal zone

As a policy statement on groundwater, these very bullets can be expanded through integrated processes of participatory groundwater management and groundwater governance. Once aquifers are mapped, for instance, it would be clear to policy makers as to *where to do what*. For instance, it would be useful to regulate exploitation of groundwater in areas that are already *vulnerable* to groundwater depletion and deterioration and promote groundwater resources development in reformed versions that ensure improved equity and efficiencies of extraction. Moreover, issues like salinity ingress into aquifers along coastal zones can be further ‘typologised’ through an aquifer mapping effort, leading to more concrete policies for such zones. A section regarding the management of spring systems within fragile ecosystems like Himalayas and Western Ghats could form another important aspect of such a policy.

Lessons from pilots will feed into policy, enabling expansion of the policy mandate on groundwater. The development of the overall legislative framework ought to evolve on the basis of such lessons and be derived from *legal guiding principles* in the reformed policy environment on groundwater.

It will be difficult to make a separation between Central and State Policies on groundwater, based on the present situation. Questions such as, “do we need a separate policy on groundwater” is bound to lead to plenty of debate and discussion. However, in the process-based groundwater governance framework, policy will have four major roles:

- Take *lessons* from the ground and convert them into robust policy statements
- Help drive more concrete ‘legislative’ frameworks
- Provide guidelines (to States and various Departments) for scaling up response strategies for different groundwater problems and situations.
- Develop a skeleton for decentralizing the process of groundwater management and disseminate the lessons that flow to it from pilots and from the broader response domain to improve capacity building efforts.

6. Conclusion

Scripted by in its agricultural hinterland, the development of groundwater resources is a story about how groundwater has enabled millions of India’s farmers to improve agricultural production over reasonably short periods of time. This has, however, given rise to serious issues around socio-ecological sustainability including public health, environment and increased levels of vulnerability to resource abuse and contamination.

Thus, from considerations of health, ecology and livelihoods, there is a clear need to develop robust mechanisms of groundwater governance along with participatory forms of groundwater management, both of which use aquifer-based approaches that have begun to find their way into the practices and policies dealing with groundwater in India. Discussions on various approaches to groundwater management have gained momentum while the question of complementary groundwater governance remains largely unresolved.

One of the significant diversions from a business-as-usual approach to groundwater resource management in India is the move away from 'infrastructure' based, 'supply-side' solutions, to more comprehensive solutions that integrated hydrogeology and engineering with sociology and economics in developing a groundwater governance framework. This framework needs to be defined through three broad elements – the content and application of science, participatory processes of resource understanding leading to community-based decisions and actions, regulatory processes derived through social, economic and ecological considerations supported by robust legislative instruments.

The science of groundwater must be recast in an interdisciplinary form integrating the concept of an aquifer as a common pool resource that has multiple roles. Participation at all levels is important in management decisions as well as in the development of a governance framework. Given the atomistic nature of India's groundwater resource development, it is important to attempt stakeholder participation at various levels – development, monitoring, analysis, synthesis and decision making.

Regulation, whether through social norms or through formal law-making, must be developed with the purpose of 'protection' of the resource as well as 'good practices', particularly processes that promote equitable and efficient use of groundwater resources. Such a regulatory function must be able to compliment participatory processes of groundwater management that are derived as outcomes of an interdisciplinary science (as synthesized above).

Finally, the processes that will help integrate science, participation and regulation will include building capacities across a range of sectors and stakeholders that will enable healthy collaboration particularly in piloting groundwater management and governance at various levels across the diverse socio-hydrogeological typology in India. Such piloting must feed into the process of legislation that keeps the common pool management practices around groundwater as a core purpose rather than a command and control type of legislation. Developing a policy is often the first objective in a groundwater governance exercise. However, it would be more prudent to develop a groundwater policy only after the first few baby steps have been taken in pursuit of piloting groundwater management in conjunction with the aquifer mapping programme that the CGWB has embarked upon at the national scale in India.

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