Catalysing Groundwater Governance Through People's Participation and Institutional Reform

Himanshu Kulkarni, Dhaval Joshi, Uma Aslekar and Siddharth Patil

Abstract India's groundwater usage is the largest in the world. Nearly, all sectors, especially rural domestic water and water in agriculture, have large-scale dependencies on groundwater resources. Groundwater exploitation, without due consideration to the concept of aquifers as common pool resources, has led to the dual problem of groundwater depletion and contamination. Groundwater depletion has also led to depletion in river flow. Competition over groundwater resources has slowly emerged as a complex problem across India's diverse aquifer typology, sometimes leading to conflict. The rise in the number of wells across the small land holdings in India has meant that groundwater extraction occurs at high granularity, making it difficult for large-scale data and information to capture the reality of problems of the ground. The social, economic and environmental consequences of groundwater over-extraction in India is as much related to the variability in the transmission and storage properties of different aquifers as it is about the diversity in the social context of people who use groundwater resources. Community-based norms on managing groundwater resources have been one of the emergent areas of responding to the crisis of groundwater management in the field. Policy, on the other hand, has been toying with conventional regulatory responses, mainly through groundwater legislation. The gap between the policy and practice of groundwater management is quite wide and requires a combination of groundwater management and governance. Institutionalizing the integration of groundwater management and governance, although seemingly challenging, has become crucial in addressing India's groundwater crises. Combining demystified science, people's participation and institutional reform to bring to the fore the concept of aquifers as common pool resources can form a solid foundation for catalysing groundwater governance in India.

Keywords Aquifer typology · People's participation · Community-based norms · Institutions

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1 Introduction

India's new government recently merged the two most important ministries—the Ministry of Drinking Water and Sanitation and the Ministry of Water Resources—dealing with water and constituted the Ministry of *Jal Shakti*. It is an interesting move, keeping in mind the constantly shifting dependencies in the water sector and the recent spate of droughts that many regions of India have experienced. Nearly, 1 billion Indians use groundwater every day, whether in agriculture, for drinking water supplies or in the context of urban and industrial water supplies (based on recent data, mainly Ministry of Drinking Water and Sanitation 2018; Ministry of Agriculture 2014; NIUA 2011). Groundwater, in particular, has received much attention, both in practice, through the focus on water conservation and recharge programmes, and in public policy, through the national aquifer mapping programme and through the more recent policy reform suggested for India's two large institutions—the Central Water Commission and the Central Ground Water Board (Jain 2017; Committee on restructuring the CWC and CGWB 2016). Moreover, the focus of managing groundwater has also figured strongly in a report on the strategic management of the programme called Prime Minister's Krishi Sichayee Yojana—PMKSY—and the work on solar power for improved management of groundwater resources from different parts of India (Shah et al. 2016; Bassi 2018).

The crisis surrounding groundwater is already hitting India hard. And it is here to stay! India became the largest extractor of groundwater in the world in the 1980s (Shah 2009). The fact, of course, became evident only after data on groundwater over-extraction emerged in the late 1990s and towards the beginning of the twenty-first century. India's groundwater extraction continued to grow through the 1980s and is still in the acceleration mode. The trend and pattern of India's groundwater extraction presents a temporal and spatial paradox. Growing dependencies in agriculture, from as less as 30% at the time of India's independence to as much as 70% after the turn of the century (Vijay Shankar et al. 2011; Ministry of Agriculture 2013), has meant that agricultural demand for groundwater is competing with groundwater sources that provide 98% of India's rural drinking water supplies (Ministry of Drinking Water and Sanitation 2018). India's towns and cities are not behind in their access to groundwater supplies. More than half of India's urban water supply comes from groundwater through formal and informal systems (Narain and Pandey 2012), while sample studies across industries show that 55% of industrial water use is based on groundwater, either as a stand-alone source or as a source that supplements surface water supplies (Perveen et al. 2012).

Such large-scale, unprecedented dependency on groundwater created a crisis surrounding groundwater resources. With the largest groundwater-depleted region of the world—the Indo-Gangetic Plains—reported through a variety of publications (Macdonald et al. 2016; Mukherjee et al. 2015), the groundwater revolution in India has been scripted by millions of farmers and ordinary citizens, essentially to bridge the gap between public water supply and the rapidly growing demand. This gap was filled by groundwater resources tapped largely through individual investments and technology innovations, both of which require a separate chapter, beyond the scope of this one. Despite more than 5000 large dams, their distribution networks and centralized water supply systems to many towns and cities, groundwater usage continues to grow in myriad ways through the farms of India's hinterlands and the by-lanes of its towns and cities. The consequences, simply put, are in the form of profound impacts of severe depletion of groundwater resources, serious effects on groundwater quality leading to groundwater contamination and ungauged effects on river flow through base flow depletion. However, what is even more intriguing is the degree of neglect by water practice and policy despite a growing dependency and deepening crisis surrounding India's aquifers and its river systems. Moreover, public water supply delivery still remains aloof of this paradox on groundwater, implying the need for a serious relook into the questions surrounding groundwater governance in India's diverse groundwater setting.

Understanding the intricate linkages between the science of groundwater and the societal aspects of the resource has become very relevant to the field of global water management (Burke and Moench 2000). The contextual diversity of India's groundwater resources cannot be complete without understanding the complex dynamics between the large-scale consumptive and productive anthropogenic demands and the subtle services that groundwater provides to the environment. The tacit competition between the demands for life (drinking water and sanitation), livelihoods and food security (agriculture), production services (industry) and ecosystem services (base flows and springs that sustain natural flows and stocks in the environment) deserves more attention than it is getting today. Adding to this is the dimension of community-managed systems of water such as the traditional concepts of water–users associations and even the more recent but eroded systems of equitable water distribution called the Pani Panchayats (Deshpande and Reddy 1990), both of which are based on the principles of managing and governing water as common pool resources.

India's groundwater footprint is quite unique and requires a different paradigm of management and governance. While synthesis of the problem of groundwater depletion and contamination is quite elaborately discussed, the specific subject of groundwater governance is actually a more recent development that needs deeper insights from the ground. Globally too, groundwater governance is being synthesized through many lenses, including that of regulation and participation (Molle and Closas 2017), also providing the opportunity to look at a fairly new topic through varied prisms. It has become necessary to revisit the subject of groundwater governance, particularly in India, because of the fuzziness between groundwater management and governance. Moreover, the need for participatory science and decentralized science-based decision-making form the two pillars on which groundwater governance thinking must move forward in India (Joshi et al. 2019). This paper delves into the dichotomy of groundwater management and governance and the need to bridge the gap between these two for groundwater governance to become an effective tool in the complex world of managing India's aquifers as common pool resources. The paper largely bears reference to groundwater governance for rural India and has major implications for agriculture and rural drinking water in India.

2 Aquifers as Common Pool Resources: Current Context

India is one of the most hydrogeologically diverse regions of the world. Two distinctly different aquifer settings dominate India's aquifer setting. Nearly, 1 million km^2 of India's surface area is underlain by unconsolidated, river and wind-blown deposits, while 1.5 million km^2 of its area is underlain by crystalline rocks—ancient igneous and metamorphic—rocks, also called 'hard-rocks'. Together, these two hydrogeologically different aquifer systems underlie 70% of India's area and constitute the two dominant regions of large-scale groundwater overexploitation. More than 80% of the region of groundwater exploitation in India is underlain by these two aquifer systems (Kulkarni et al. 2015; CGWB 2017). Moreover, it is interesting to note how rural and urban habitations in India are distributed across its diverse aquifer settings (Fig. 1).

The great dependency of India's major sectors on groundwater and the emerging crises of depletion and contamination has meant growing competition and potential conflicts over groundwater resources (Kulkarni and Vijay Shankar 2014). Such competition is evident within each sector (farmer versus farmer) but is clearly emerging in the form of inter-sectoral competition (agriculture versus urban demands), leading to conflict. Many villages face acute drinking water scarcity, especially during summers, as a consequence of large-scale groundwater irrigation throughout the year. Not many of these conflicts are reported except the one about a beverage company and a village panchayat (ELRS 2012).

India has the largest number of wells in the world. There are an estimated 29 million irrigation wells today across the country (5th Minor Irrigation Census, Government of India). However, Shah (2009) had estimated 30 million irrigation wells in India. While one can continue to argue about the actual numbers, it is interesting to note how, in the last couple of decades, the rise in bore wells and tube wells have enabled easy access to many users from greater and greater depths. For instance, during the two decades from 1986 to 2006, the number of dug wells in the Malwa region of Madhya Pradesh increased by one and a half times, while the number of deep tube wells increased by thirteen times (Kulkarni et al. 2015), clearly indicating that not only has the well-density significantly risen, but the competition over chasing groundwater from greater depths has also gone up significantly. In other words, groundwater users are competing for water in different aquifers, both through putting more sources on their lands but also ensuring that the deepest wells in a region are also on their land.

India's average landholding is estimated to be of the order of just over a hectare. The highly granular nature of groundwater usage across India's diverse aquifer typology creates a variety of tensions. The mismatch of hydrogeological boundaries (aquifers) and political–administrative boundaries (e.g. land-holds, villages, talukas or blocks, districts, states) is evident in myriad forms. However, this mismatch has resulted in tensions across the entire typology of India's aquifer systems, many examples of which are available in Kulkarni and Patil (2017). Conflicts over groundwater are a result of early competition (Kulkarni and Vijay Shankar 2014).

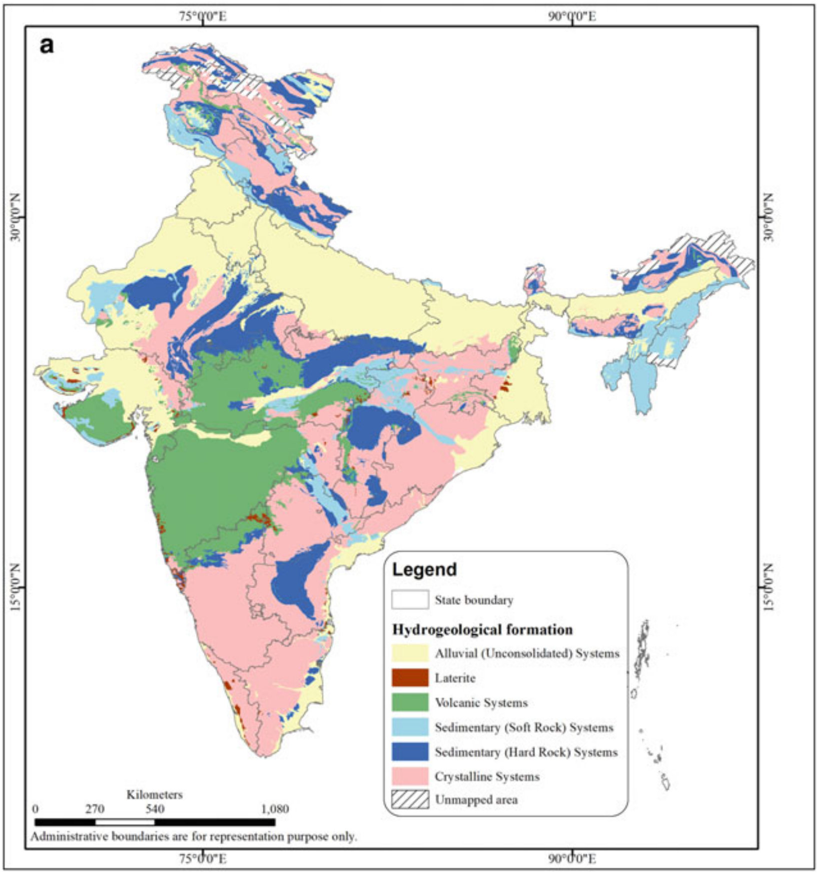

Fig. 1 Generalized aquifer settings in India (**a**)—modified after COMMAN, 2005 and updated significantly by ACWADAM recently—and the distribution of rural and urban habitations based on these aquifer settings (**b**). *Note* Himalayan and sub-Himalayan region has been consolidated as 'Mountain' in Fig. 1b

Users having a common goal of water usage, e.g. agriculture or industry, readily accept and live with competition for long periods.

Social, political and even legal battles ensue because of the domain of allocations made possible through quantitative estimation of stock and flow of surface water (Kulkarni and Patil). Surface water is commonly sourced, accessed and distributed through 'public' systems of water supply. Hence, conflict and contestation take on the shape of a variety of responses ranging from protests to protracted legal battles over such water. Administrative (land) boundaries complicate matters further, leading to a variety of transboundary disputes. On the other hand, groundwater in India, and perhaps from many other parts of the world, is sourced in a dispersed and fragmented manner. Boundaries, quantities and interdependencies are less visible or measurable as compared to surface water resources, resulting in

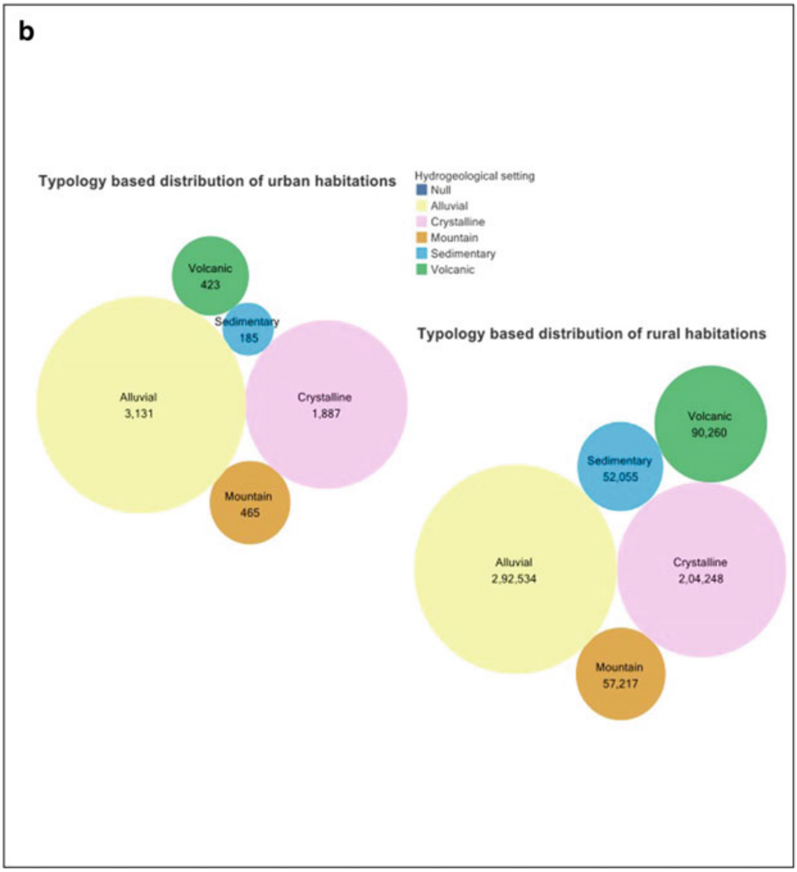

Fig. 1 (continued)

groundwater resources being subjected to intense and intricate competition between users and uses before conflicts become open (Kulkarni and Vijay Shankar 2014). Moreover, individual access and complex distribution systems from multiple sources lead to failure of sources that in turn causes severe water stress. Social and economic drivers often lead to haphazard access and distribution patterns of groundwater in India's large agrarian landscape. Often, understanding of groundwater—particularly aquifers—is neglected in creating improved access and distribution. In pursuing improved access, the number of sources (wells) increases at the expense of an intense competition between users and types of usage over a common resource (aquifer). On the other hand, competitive extraction and falling water levels leads to a marginalization and shutting out of the lower castes, typically marginal farmers and the landless, from well-ownership altogether (Dubash 2002).

Groundwater overexploitation maybe defined as a situation in which, for some years, average abstraction rate from aquifers is greater than of closer to the average recharge rate (Custodio 2002). Large-scale, granular groundwater access in India has led to serious impacts of groundwater depletion and contamination. While alarm bells rang louder when global estimates, including particularly the estimates on groundwater depletion and contamination in the Indo-Gangetic region were presented by international researchers (Rodell et al. 2009; MacDonald et al. 2016), the latest figures presented in CGWB's periodic assessments clearly state the glaring facts. Some 32% of India's sub-district administrative units—blocks and talukas—have become unsafe (semi-critical, critical or overexploited) or have high levels of salinity (CGWB 2017). What is even more glaring are the degrees of contamination of groundwater by fluoride and arsenic. The Ministry of Drinking Water Supply and Sanitation (2018) reports that we have problems of high Fluoride in 203 districts, Ironin 206 districts and Arsenic in 35 districts. Fluorosis is estimated to afflict 65 million and Arsenicosis around 10 million people in India.

Apart from the above, one of the largest knowledge gaps in India pertains to the environmental role of groundwater. Large-scale inclusion of groundwater in both, global development reporting and the ecosystem debates is relatively recent (CGIAR 2015; WWAP 2012). Groundwater resources are as important in ecosystems as they are in providing services to anthropogenic needs such as domestic, agricultural and industrial water supplies. Aquifers are relevant to both ecosystems such as forests and wetlands and their ecosystem services. Forests and wetlands have figured in discussion on ecosystem and ecosystem services for a long time now. Groundwater, only recently and not as much! As aquifers are 'developed' and then subsequently over-extracted, one of the first visible impacts is often in the form of base flow depletion, with streams and rivers drying up (Macdonald et al. 1995). The stocks and flows in aquifers, determined primarily by their transmission and flow characteristics, provide a variety of services to both human and ecosystem needs as aquifers also support a variety of habitats, primarily through seeps, springs and base flow contribution to river flows. In a monsoonal climate, such as in India, base flow from groundwater is a relatively small but seasonally significant flow that keeps streams and rivers flowing during the dry periods of the annual hydrologic cycle.

There are clear social, economic and environmental consequences of groundwater depletion and contamination, leading to serious forms of morbidity and even mortality. The proliferation of wells in India is a classic example of how increased individual access to groundwater has often defeated the goal of managing aquifers as a common pool resource. Community wells have given way to individual access such as is evident in some programmes of the Government of Maharashtra, for instance, where the slogan of 'whoever asks for a well or a farm pond, will be given one (by the State)'. Consequently, the concept of 'water resources held in trust' by the community has been replaced by a competitive and conflict-ridden arena of sourcing, access and distribution of groundwater resources. The crisis of groundwater in India can be addressed only through a return to the principles of common pool resources, principles that not only address converting competition to co-operation but also help in bringing communities closer to their aquifers.

Having said that, it is also important to recognize that aquifers in India are as diverse as the social milieu that define groundwater usage. The social milieu is

Table 1 Estimated percentage of areas in each broad type of aquifer system, which is under some degree of groundwater exploitation

Aquifer typology	Area (km^2)	Percentage of total area which is in the three categories of groundwater exploitation (%)
Alluvial (unconsolidated) systems	931,832	18
Mountain systems	525,067	0
Volcanic systems	525,036	7
Sedimentary (soft rock) systems	85,436	0
Sedimentary (hard rock) systems	194,798	2
Crystalline (basement) systems	1,023,639	10
Total	3,285,808	38

Note Aquifer typology is based on Kulkarni (2005), Kulkarni et al. (2015) and estimates of groundwater exploitation are based on CGWB (2017)

defined not only by the social and economic context of a region—which again is often rooted in the culture of a region—but also on the system of aquifers and their status of exploitation and contamination. Aquifer systems are defined primarily by the geology of a region and by the properties of rock types that govern the accumulation and movement of groundwater in aquifers. The storage capacity of an aquifer, known as storativity and the capacity of the aquifer to transmit groundwater, known as transmissivity are called aquifer characteristics. Both these vary, depending upon how different geological formations constitute aquifers. Table 1 shows the distribution of India's broad aquifer systems and the percentage of the areas underlain by aquifers under various degrees of exploitation, in each of these aquifer systems.

3 Groundwater Management and Governance: The Practice and Policy Dilemma

Civilizations in different parts of the world have been depending on groundwater resources for many centuries. The legacy of groundwater usage until the nineteenth century involved a combination of widespread access from shallow sources such a community dug wells, springs and qantas followed by inventions that involved human and animal traction (after Moench et al. 2013), through technologies such as the Persian Wheel. One can therefore presume that such systems must have included a strong component of governance by the social and political systems prevalent at different periods in history. The unprecedented growth of groundwater dependency across the world, and especially in Asia, is often cited as a revolution by millions of users, especially farmers (Fornés et al. 2007; Shah 2009), who, largely with their own investments created access to groundwater for irrigation. This growth has fuelled the improved security of water supplies, both for domestic and agricultural needs across the world. At the same time, it has clearly brought about a shift from community-governed systems of shared sources and resources to individual, access-driven competition around such resources, especially aquifers.

India's annual groundwater extraction is estimated to have increased ten times since India became independent (estimated from Shah 2005). India's groundwater trajectory, as a consequence of the almost invisible transition from a dominantly surface water dependency in agriculture to an unprecedented dependency on groundwater for agriculture and domestic water supplies, both in rural and urban settings, has led to a set of serious consequences, the main ones being:

1. The shift, during the last century, from a community resource to a fragmented resource accessed by millions. The division of the resource (aquifers) through such millions of sources (especially wells) has come into conflict with the fundamental principles of managing aquifers as a common pool resource.
2. The competition between various users and types of use has led to critical levels of groundwater depletion that is often coterminous with serious issues of groundwater contamination.
3. Nearly, the entire drinking water supply in rural India is met from groundwater. While the average annual demand for drinking water in a typical India village is negligibly small when compared to the demand for irrigation, the competition between these two demands has surely seen only one winner—irrigation. Drinking water security is seriously endangered in very many villages of India.
4. Groundwater is largely invisible and requires an understanding that is based on carefully collected, analysed and interpreted data. While available data on groundwater in India is sufficient to be indicative of a variety of problems, the data is not representative enough to stimulate robust decision-making at appropriate scales.
5. Lastly, conservation and recharge efforts are becoming increasingly popular across India; while many such efforts are genuine, their overall benefits to the management and governance of groundwater remains limited, especially with regard to the free riding (of such benefits) through unsustainable groundwater usage.

A variety of responses have emerged in developing examples and demonstration of sustainable groundwater management in India. The Hivre Bazar experiment from Maharashtra has been a torch-bearer of combining supply- and demand-side reforms through decentralized institutions of governance (Gram Panchayat) in a drought-prone, hard-rock aquifer system in India (Singh 2012). Apart from this experience, whether it is the scaled approach of using a hydrological water balance to develop crop-water budgets under the Andhra Pradesh Farmers Managed Groundwater Systems (APFAMGS) (Das and Burke 2013) or the intensively engaging programme of developing a social protocol integrating hydrogeology and people's participation under the Participatory Groundwater Management Programme (PGWM) in a variety of locations across five or six different states, there are certain common features that have emerged through such efforts (Ghose et al. 2018). These features, among many nuanced aspects of hydrological and socio-economic importance, broadly include the following:

1. Demystified understanding of hydrological units such as watersheds and hydrogeological units such as aquifers.
2. A systematic quantification of (ground)water usage that is indicative of various demands over water, means of supply and their numbers and availability of water, often according the various seasons during a year.
3. Participatory systems of data collection, collation and analyses.
4. Decision support based on basic inferential aspects of analysed data, such as the developing of a groundwater management protocol that is customized to local conditions.
5. Participatory action, often at the community level such as the implementation of systematic conservation and recharge measures, efficient application of water, changes in cropping systems and protection of drinking water sources.

Hence, the success of many of these initiatives has depended on how each of the above have evolved with regard to the local context and the nature of organizations and collaborations that have provided knowledge and facilitation support to the local rural communities. These organizations have been in the form of Civil Society Organisations, Government Departments or even local leadership that have anchored external inputs to raise and nurture community-level systems of decision-making on groundwater management. However, one of the important questions that is raised with regard to such initiatives on community based, participatory groundwater management, is that of why have these initiatives remained ‘islands of success’ without being replicated or scaled out to other, even neighbouring locations. Moreover, after an initial phase of success, participatory processes of groundwater management cannot often be sustained in time.

With this background, it is important to examine the challenges posed to such strategic approaches—management objectives around certain key hydrogeological paradigms (called protocol) and their impacts of groundwater management that have precluded the scaling out in both space and time (Table 2).

Most efforts in India on coming to terms with the groundwater crises focus on bringing communities together to develop and act upon a set of supply and demand management actions. These efforts try to integrate aquifer understanding with community participation to achieve improved levels of efficiency and equity in groundwater usage (Ghose et al. 2018). However, as may be seen from the table above, the challenges are mainly in the form of a variety of externalities that have solutions largely in the ‘policy’ arena. Moreover, it is easier to develop social norms around groundwater such as a village-level groundwater management protocol but it is well-nigh impossible to both, sustain the protocol and gain formal acceptance to the social norm through existing institutional mechanisms.

Hence, the large gap between the practice of participatory groundwater management and current policies dealing with water forms the major stumbling block in achieving any form of scaled response to the crises of groundwater depletion and contamination in India.

Table 2 Synthesis of protocols and impacts of community-based groundwater management in India and the main sets of challenges to sustain these impacts

Broad protocol of groundwater management	Impact through key measures of success	Hurdles or challenges in sustaining the impact or measure of success
Conservation and recharge including managed aquifer recharge	Ensuring optimum recharge and protecting catchments from degradation, which in turns ensures both groundwater level and groundwater quality maintenance in aquifers	Operation and maintenance of conservation measures are not sustained, encroachment and land-use/land-cover changes on natural and conserved recharge areas; government programmes also provide farm-level conservation that takes priority over community level conservation and recharge efforts
Measure of using and managing sources through efficient use of wells and springs	Efficient extraction and application of groundwater leading to improved productivity of sources	Competition cannot be avoided in the absence of any legislation; competition includes community drinking water wells versus individual wells; competition leads inefficient extraction rates that affects the status of aquifers; policy externality often brings incentives and subsidy through individual wells
Regulating withdrawal rates of groundwater using energy as an instrument of regulating pumps	Sustained rates of pumping leading to improved efficiencies in pumping, extraction and wells	Energy as an externality is a key factor (Shah et al. 2012)—individual connections on wells often conflicts with groundwater-based Water User Groups; energy is often used as a political instrument where free and unlimited power become instruments of gaining votes before elections
Protection zones including protecting drinking water sources by controlling source-to-source interference and regulating the depth of wells	Drinking water secured from competitive extraction and drilling	Schizophrenia of digging and drilling—maximizing sources—especially during a drought; the disconnect between land-rights and groundwater leads to multiplication of sources as land ownership changes with land division; droughts leading to schizophrenia of drilling; uncontrolled water markets where groundwater from farmland is transported to towns, cities and industries

(continued)

Table 2 (continued)

Broad protocol of groundwater management	Impact through key measures of success	Hurdles or challenges in sustaining the impact or measure of success
Regulating groundwater extraction by managing crop-water budgets	Efficient demand management of groundwater in agriculture based on simple but effective groundwater balances	Uncertain crop markets make the choice of sustainable agriculture difficult; iniquity in land holding, and the decentralized political economy imply that practices of groundwater management and conducive policies to sustain them are seldom in resonance
Comprehensive management of groundwater using a combination of the above measures and integrating these with water user co-operatives	Integrated groundwater management that is inclusive of efficient and equitable access and distribution of groundwater as a CPR	Market as an externality with consequences for labour, returns and water conservation forms the main hurdle; the absence of pro-active legislation and incentives form the main challenges in scaling up practices of aquifer-based, participatory groundwater management

4 The Dichotomy of Groundwater Management and Governance

Groundwater governance is defined in multiple ways. Groundwater governance is the art of co-ordination between administrative action and decision-making at different jurisdictional levels, at the same time being a process involving groundwater management through the application of responsibility, participation, information, transparency, custom and rule of law (Varady et al. 2013). On the other hand, groundwater governance is better thought of as the governance of aquifers given their vulnerabilities and importance in providing essential reserve supplies of water (https://www.oecd.org/cfe/regional-policy/8-Tour-de-table-Andrew-Ross.pdf). While defining a framework of groundwater governance in the USA, Megdal et al. (2015) highlight three problems as priorities within this framework—water quality and contamination, conflicts between users and declining groundwater levels.

Currently, the lack of robust groundwater governance mechanisms, mainly in the form of institutional frameworks including legislation, limits the impacts of processes such as participatory groundwater management. In a recent publication on the challenges and prospects of water governance in India, Singh et al. (2019) define water governance as the set of rules, practices and processes through which decisions for the management of water resources and services are taken and implemented. Often, water governance becomes a paradigm that must be developed centrally. In other words, it becomes synonymous with policy making.

However, given the granular nature of the problem itself, setting down a centralized process of governance will only widen the divide between groundwater management and governance. South Asia's groundwater problem, for instance, requires groundwater governance that deals with a clear integration of conjunctive management of rain-surface water-groundwater, addressing the energy-irrigation nexus, participatory groundwater recharge, conveying water through pipes rather than channels, but most significantly dealing with externality (Shah 2009).

The paradox of pushing for participatory forms of groundwater management in India while attempting to deal with governance through stringent instruments of legislation represents a clear dichotomy between thinking on groundwater management and governance. Table 3 highlights the differential context of groundwater management and governance and attempts to identify gaps that require a fresh approach from the current paradigms of water governance, based on experiences on PGWM by ACWADAM in Maharashtra (Aslekar et al. 2013; Rangan 2016). Hence, the meaning and relevance of groundwater governance in India can be culled out as the process that enables institutional support to help sustain aquifer-based, decentralized participatory groundwater management bearing in mind the objectives of efficiency, equity and sustainability.

While developing the framework for institutions around groundwater management and governance, one fundamental question that arises out of the current dichotomy between groundwater management and governance is: 'Why legislate if people participate in the management of groundwater'? There are two fundamental reasons for an institutional reform on groundwater in India, including a large overhaul to legislation. But before getting to this point, it is important to answer the question of why legislation, as part of the larger institutional reform, is necessary. Firstly, the quantitative and qualitative change in the significance of groundwater resources and the growing dependency of India's population on these resources requires an institutional overhaul, including major changes in water laws in India. The regulatory framework governing groundwater has not been updated since the nineteenth century and is based on a mistaken understanding of hydrogeology and the present legal regime gives precedence to individual interests of landowners precluding the basis for aquifer-wide protection measures (Cullet 2019).

A new paradigm to overcome the gaps between the practice of participatory groundwater management and policies of water governance is to bring these two as close to each other as possible. Rather than making governance the sole responsibility of governments, we need to craft a carefully designed architecture of partnerships, where all primary stakeholders get deeply involved in the collective endeavour of participatory water governance. Such partnerships are even more relevant when we think about participatory groundwater governance because the concept of command-and-control regulation and established institutions of governance become irrelevant when millions of users now control the usage of groundwater. Rather than disciplining the users through formal processes of regulation, it is more sensible to gain their confidence through a variety of participative

Table 3 Narrowing the gap between management and governance—a broad-based template for actions

Broad parameters for sustainable groundwater management	Major challenges in developing and/or sustaining the parameter of management	The most important element that defines groundwater governance in addressing the challenge
Efficient groundwater usage defined by optimal extraction for different uses	Inherent complexity of groundwater settings, lack of data and information, the externality of energy and the poor understanding of energy-groundwater relationships	Information and data at appropriate scales, a finer understanding of groundwater and energy and defining groundwater efficiency as a measure of aquifer productivity rather than water productivity
Equitable distribution leading to fair and just supply of groundwater	The complicity of land and water rights; priorities of groundwater usage—economic (irrigation) returns take precedence over social (drinking water) and ecological (base flows) returns	Political commitment along with robust legal provisions that enable a protection of social water right over economic ones
Community-level decision through formal institutions	Breakdown of co-ordination among stakeholders; weak decision support due to lack of data, facilitation and conflict resolution	Institutional support—decentralized support by public agencies dealing with groundwater and legislation that mainly addresses externalities of free riding the benefits of community-led decentralized decisionsby formal governance institutions
Sustainable economic returns while ensuring environment security	Misplaced subsidy, uncertain markets and skewed returns (crops requiring more water generally fetch higher and steady returns)	Reforms in markets and market support, especially to farmers

processes leading to collective decision-making in managing and governing groundwater resources.

5 Institutions: Towards Integration of Groundwater Management and Governance

Ostrom (1990) "design principles" in the management of common pool resources such as aquifers make a clear reference to resource pool, the local scale of operation and sustained co-operation among users of the resource. The design principles are:

1. Clearly defined contents and boundaries of the resource and exclusion of external untitled parties;
2. The appropriation and provision of common resources that are adapted to local conditions;
3. Collective-choice arrangements that allow most resource appropriators to participate in the decision-making process;
4. Effective monitoring by monitors who are part of or accountable to the appropriators;
5. A scale of graduated sanctions for resource appropriators who violate community rules;
6. Mechanisms of conflict resolution that are cheap and of easy access;
7. Self-determination of the community recognized by higher-level authorities; and
8. In the case of larger common pool resources, organization in the form of multiple layers of nested enterprises, with small local CPRs at the base level.

The design principles can be further broken down into primary and secondary factors while understanding community groundwater management in India. At the same time, it becomes important to note the common features of experiences in both Community Management Responses to groundwater in rural India (COMMAN 2005) and the evolving experience in Participatory Groundwater Management (PGWM) from different parts of India (ACWADAM 2014; Ghose et al. 2018). These are listed below:

- Both community approaches and PGWM empower communities to make informed choices around the question of rural water security.
- Groundwater management is not necessarily interpreted in terms of developing locally agreed controls.
- Symptoms and responses to groundwater problems, especially depletion, vary despite underlying common causes.
- Measures to augment groundwater are more acceptable than those to conserve it.
- Hydrogeological advice may help assess the risk of losing conservation gains.
- The limitations of state's interventions for regulating groundwater use through punitive measures can be circumvented to a large extent by enabling communities to make informed choices—such as instances of banning and regulating the depth of new borewells, shifts in cropping pattern, sharing of borewells, etc.
- The incongruence between scales of groundwater management and aquifer dynamics along with the issue of exclusion of certain stakeholders from the management group are the central challenges to the development of community-based organizations for groundwater management.
- The heterogeneity of communities remains a big challenge in achieving success in participatory, community-driven groundwater management, especially in regional aquifer systems.
- Dealing with large externalities such as urbanization, energy incentives and land-use changes is the biggest challenge for efforts in community-based groundwater management, not to mention the difficulty in incentivizing peoples' participation on groundwater management, through public policy instruments.

Whether it is dealing with externality or with the limitations resulting from lack of information (on the scale of aquifers) or proceeding beyond supply-side management into the domain of demand-side groundwater management, the conceptual framework of robust institutions, and therefore, the broader reference to groundwater governance become significant. In moving forward, it is important to couple participatory forms of groundwater management with decentralized groundwater governance in India. In doing so, it is important to remember that transdisciplinary, demystified science should become the basis for participatory decision-making leading to developing an institutional system of groundwater governance based on a relevant protocol of groundwater management. The process itself could be based on four basic steps:

1. Mapping of aquifers leading to participatory responses that include direct, indirect and community instruments of management.
2. Special emphasis on securing rural drinking water supply, in terms of assured quantity and potable quality of water.
3. Management plan will depend upon the groundwater setting, aquifer geometry, state of groundwater usage including agriculture/industry/rural–urban interface and other such factors.
4. A legislative framework that goes beyond a typical command-and-control legislation to a more reformed legislative instrument that compliments and protects the socially accepted norms of participatory groundwater management.

In a recent attempt to reform India's water sector, the Mihir Shah Committee (Shah 2016) has recommended the constitution of the National Water Commission, which builds enduring partnerships between government, academia and civil society and functions through a decentralized, transdisciplinary river-basin structure. The main purpose behind the recommendations in the report is to reform India's Water Governance. As part of the same report, it becomes relevant to summarize the reform included specifically for the groundwater sector. The main suggestions for groundwater governance deal with reforming the topmost groundwater institution in the country—the Central Ground Water Board (CGWB). These suggestions are summarized as:

- India must engage with the issues of groundwater depletion and contamination by looking beyond groundwater assessment and permits. This can be done by strengthening the institutional architecture on water in general and groundwater in particular, the latter through a major reform within the CGWB and all the state groundwater departments/directorates without whom the CGWB simply cannot function.
- At the topmost echelons in the institutional structure of the country, the reform must include bringing in an interdisciplinary approach to groundwater institutions through:
  - Expansion and enrichment of the human resource profile of the CGWB and all other such organizations involved in groundwater governance.

- Revive and reform State groundwater departments/directorates and make them more accountable to catalyse decentralized groundwater management and governance.
- Aquifer mapping to groundwater management—enduring partnerships with academic and research institutions, as also civil society organizations.
- Build capacity on the equitable, efficient and sustainable management of aquifers in India.
- A deeper knowledge of grass-roots realities on groundwater in different parts of the country will be possible for policy makers and people in governance only through a deeper engagement with communities, themselves a diverse set of stakeholders in groundwater management and governance.

A one-size-fits-all approach of groundwater management and governance becomes irrelevant under India's aquifer and socio-economic diversity. Table 4 provides a synthesis of the relevance of individual elements of the protocol of groundwater management to the six broad aquifer settings in India. The synthesis uses their hydrogeological features, the main threats to the aquifer systems and the most relevant protocols that will require to be prioritized through a potential groundwater governance lens.

6 Conclusion

The consequences of unrecognized large-scale groundwater dependency are evident in the form of aquifer depletion, groundwater contamination and drying up of rivers. Restoring aquifers requires a strategic combination of managing groundwater resources while establishing a robust system of decentralized groundwater governance (Kulkarni et al. 2015; Joshi et al. 2019). The process of ensuring a seamless integration of efficient and equitable groundwater management to sustainable groundwater governance must firstly include demystified science leading to the development of knowledge, data, skills and understanding of groundwater resources at any given location. Such understanding will lead to the decision support to a variety of stakeholders, especially when the stakeholders participate in the building up of the knowledge and understanding on groundwater.

Based on such decision-making, co-operation between stakeholders can evolve and must be supported through robust systems of governance that include socially normative regulation backed by formal legislation, which together will define the institutional structure of groundwater governance in India.

Framing groundwater governance as the governance of aquifers is important so as to instil confidence and belief in managing groundwater resources as Common Pool Resources (CPR). In doing so, groundwater management must become inclusive of the need to shift the focus of plans and practices from 'sources' of groundwater to the 'resource'. Lastly, creating a pro-active policy environment that embraces community participation in developing the understanding on groundwater

Table 4 Broad canvass of groundwater management protocols across India's diverse aquifer typology

Aquifer typology	Hydrogeological character and situational elements including potential threats	Relevance of specific elements of groundwater protocol in prioritizing mechanisms of groundwater governance
Himalayan mountain system	Springs and streams fed by glaciers, snow melt and rain along with discharges from low storage, moderately transmissive aquifers. Estimates indicate the presence of 2 million springs that support at least 60% of the population. Increasing urban pressures leading to a competition between wells, bore holes and spring water, sometimes from the same aquifer. Evidence of long-term decrease in precipitation, changing land-use and land-cover and changes in ecosystem elements like wetlands are leading to depleting water sources, especially springs	Springshed management, including protection of recharge areas as part of conservation; protecting and managing the springs themselves from competition by wells in the same aquifer; Spring-water management planned on the basis of spring-discharge and variability in this discharge; Spring-water distribution is possible largely through gravity-based systems, with exogenous energy being reserved only for lifting naturally available spring water and not for extraction from the aquifer; Protecting a spring source from interference with artificially created sources like wells (many of which have extraction devices like energized pumps) is necessary; crop water budgeting in mountain agriculture can be planned on spring-discharge seasonal variabilities in discharge; groundwater user groups can be designed around both, individual springs or a cluster of springs as a comprehensive strategy of groundwater governance
Alluvial system	Large storage, transmissive aquifers that are either heavily depleted due to over-extraction or are still in a state of reasonable balance. Springs, seeps, wetlands, lakes are coming under pressure from intense competition with tube well drilling. Major challenges in groundwater quality, including arsenic and even radioactive elements. Groundwater access is challenged in some areas by flood-proneness	Recharge activities should be based upon the geometry and situation of aquifers; natural recharge areas may be distant from the areas where extraction takes place; generally, well yields are high and reasonably consistent in an area, so, the focus should be on avoiding undesired competition through lateral interference of wells; controlling heavy duty individual irrigation wells becomes a priority through managing energy inputs; crop water budgeting may be effective if groundwater balances at the scales of villages are attempted (and even if these are not representative of aquifer-level groundwater balances); water user groups or co-operatives have to be a larger scales or clusters for sharing both controls and benefits

(continued)

Table 4 (continued)

Aquifer typology	Hydrogeological character and situational elements including potential threats	Relevance of specific elements of groundwater protocol in prioritizing mechanisms of groundwater governance
Sedimentary systems (hard and soft)	Pockets in different parts of India. Local and regional aquifers with variable rates of extraction and depletion. Larger issues around the close coherence of sedimentary aquifers with forests, tribal hinterlands and potential mineral resource hot-spots. Industries around mining centres and associated urbanization lead to tension between sectoral groundwater usage. Increasing impacts of deforestation, mining, tourism and industrialization, affecting both, the quantities and quality of groundwater resources	The most diverse range of aquifer properties implies the application of strategic conservation and recharge; managing energy through a systematically developed range of pumping systems that can sustain highly variable well yields; hence protecting the lower ranges of well yields is important; a combination of well interference zones along with depths of drilling becomes significant; given the variability in scales, groundwater balances and crop water budgeting needs to be undertaken at multiple scales ranging from villages, aquifers to larger watersheds; groundwater user co-operatives need to be integrated through an integration of more local village-level user groups
Volcanic system	Most heterogeneous aquifers in India. Host to the largest numbers of traditional large-diameter dug wells. Springs at the source regions of many major rivers. Competition dynamics between large dams and wells and between different kinds of wells Increasing impacts of intensive agriculture including high water demand crops, effects of deforestation and tourism on aquifers. Significant reduction in base flows to rivers	Integrated watershed management is one of the best instruments for managing groundwater recharge and initiating conservation in the hard-rock aquifers of India; efficient management of the shallow aquifers through traditional large-diameter wells forms the backbone of managing hard-rock aquifers; reviving shallow unconfined aquifers and efficient pumping of dug wells using energy more efficiently; highly variable well yields imply a common rate of extraction, preferably at the lower end of the well-yield range in hard rocks along with a control on the depth of wells and bore holes; this will reduce competition but also reduce vertical interference between aquifers while ensuring protection of drinking water; crop water budgeting on the basis of aquifer-level groundwater balances are desired while aggregating water user groups into a larger federation of such co-operatives
Crystalline system	Intense competition over depths of wells—mainly through bore holes. Aquifers are largely local, but deep and extensive weathering of crystalline basements has produced some regional aquifer systems. Intensive use for agriculture and also in rapidly urbanizing centres. Large volumes are extracted in many parts. Urbanization and deforestation are the major threats	

and generating knowledge on aquifers, communities and ecosystems is most important. Such an environment will enable the agencies of governance such as PRIs to take improved decisions and undertake actions that will lead to sustainable, efficient and equitable usage of groundwater.

Finally, on a more practical front, enabling reforms in key areas of groundwater management and governance is the most fundamental step in ensuring sustainable groundwater management. Participatory processes of management can lead to a socially normative protocol where community decisions are documented and accepted through institutional instruments such as resolutions of the village gram-sabhas (local instruments of governance under the gram panchayats—village levels elected democratic institutions of governance vested under the Constitution of India). Such social norms have a significant weight as they evolve through a continuous dialogue that is the hallmark of democratic decision-making. At the same time, it is difficult to say whether such norms are safe enough from 'free riding' through an externality such as large-scale drilling and extraction in neighbouring villages. Conventional legislation usually adopts a command-and-control approach to law making and implementation and may often become counter-productive to producing social norms. Moreover, states in India develop their own groundwater legislation. Hence, the tendency of legislation is to be constituted by a reasonable broad set of legal provisions and rules.

The concept of decentralized governance, given that the actual decision-making on groundwater will be vested at the village or sub-district levels, becomes quite relevant to India's atomistic groundwater problem. Reconciling legislation to the nuances of a decentralized normative framework will be challenging. Hence, a new approach to developing legislation on groundwater could actually include protecting the social processes developed under a participatory, decentralized normative frame. Moreover, it could further link up to protecting not just aquifers but also the larger ecosystem, thereby also demanding a strong overlap with other legislation such as legislation in agriculture, urban development and even on forests and the environment.

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