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INDIA GROUNDWATER GOVERNANCE

CASE STUDY

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PREFACE

Groundwater comprises 97 percent of the world's readily accessible freshwater and provides the rural, urban, industrial and irrigation water supply needs of 2 billion people around the world. As the more easily accessed surface water resources are already being used, pressure on groundwater is growing. In the last few decades, this pressure has been evident through rapidly increasing pumping of groundwater, accelerated by the availability of cheap drilling and pumping technologies and, in some countries, energy subsidies that distort decisions about exploiting groundwater. This accelerated growth in groundwater exploitation—unplanned, unmanaged, and largely invisible—has been dubbed by prominent hydrogeologists "the silent revolution." It is a paradox that such a vast and highly valuable resource—which is likely to become even more important as climate change increasingly affects surface water sources—has been so neglected by governments and the development community at a time when interest and support for the water sector as a whole is at an all-time high.

This case study is a background paper for the World Bank economic and sector analysis (ESW)—entitled "Too Big To Fail: The Paradox of Groundwater Governance"—that aims to understand and address the paradox at the heart of the groundwater governance challenge in order to elevate the need for investing in and promoting proactive reforms toward its management. The project examines the impediments to better governance of groundwater, and explores opportunities for using groundwater to help developing countries adapt to climate change. Its recommendations will guide the Bank in its investments on groundwater and provide the Bank's contributions to the GEF-funded global project—"Groundwater Governance: A Framework for Country Action."

Five countries—India, Kenya, Morocco, South Africa, and Tanzania—were selected as case studies to understand the practical issues that arise in establishing robust national governance frameworks for groundwater and in implementing these frameworks at the aquifer level. This report describes the Indian groundwater governance case study.

The case study focused on the national, state and local levels. At the national and state levels, it analyzed the policy, legal, and institutional arrangements to identify the demand and supply management and incentive structures that have been established for groundwater management. At the local level, it assessed the operations, successes, and constraints facing local institutions in the governance of a number of aquifers within peninsula India, on the coast and on the plain of the Ganges river valley.

The situation with groundwater use in India is well described in a number of recent publications, such as Deep Wells and Prudence (World Bank 2010) and Taming the Anarchy (Shah 2009) and several GWmate papers. The problems of over-abstraction in India in both rural and urban settings are well known, with aquifers being depleted in the hard rock terrain of peninsula India, in the coastal regions, and in the sedimentary aquifers of the Ganges valley. This report also draws attention to the threat from pollution – long before they are depleted, some aquifers will become unusable because of industrial pollutants, human wastes, and agricultural chemicals. These problems are not unmanageable. The report gives examples where far-sighted village councils have taken charge of over-abstraction and brought it under control; where polluting industries have reformed their practices and now use their waste streams for productive purposes; and where one municipal corporation has taken the brave step of attempting to introduce volumetric charging in order to introduce some demand management and to accumulate sufficient finances to develop additional sources of supply.

In spite of the anarchy (to use Shah's term) in groundwater development in India, this report implicitly believes that the current problems with groundwater management can be overcome if governments work with groundwater users rather than attempting to regulate and control them; if technical solutions are used judiciously where there are clear net benefits; and if demand management is implemented where opportunities arise. This will be far from easy – it will require a major shift in culture from the top. Barriers between both national and states bureaucracies and between the powerful water using sectors (irrigation, industry and urban development) will need to be removed. Water agency staff will face a major cultural shift from engineering based supply approaches to water resources protection, wherein they share responsibility and information with communities of groundwater users. Water users themselves will need to gain a better understanding of the shared nature of groundwater and the need to protect it from pollution if they are to be successful managers. All this will require a completely different approach to governance.

The report provides an outline of how this could be achieved by initially working within the present legal and administrative framework, while developing a parallel track of governance reforms. While the way forward can be envisaged from this analysis, putting it into practice will require a major commitment from the governments of India with assistance from the international community.

ABBREVIATIONS AND ACRONYMS

AMC	Aurangabad Municipal Corporation
APFAMGS	Andhra Pradesh Farmer Managed Groundwater Systems Project
AP	Andhra Pradesh
BIS	Bureau of Indian Standards
bgl	Below ground level
BWMHR 1998	Biomedical Waste (management and handling) Rules
CBGWM	Community-based groundwater management
CG	Central government
CGB	Central Groundwater Board
CGWA	Central Ground Water Authority
CGWQAA	Central Groundwater Quality Assessment Authority
CJ	Court judgments
CPCB	Central Pollution Control Board
CRZN 2010	Coastal Regulation Zone Notification
CWC	Central Water Commission
CWPRS	Central Water and Power Research Station
EPA 1986	Environmental Protection Act
ESW	Economic and Sector Work
GEF	Global Environment Facility
GoI	Government of India
GIPU	Groundwater Information and Planning Unit
GW-MATE	Groundwater Management Advisory Team
FAO	Food and Agriculture Organization
HP-I	Hydrology Project – Phase 1
HP-II	Hydrology Project – Phase 2
IA 1968	Insecticide Act
IDA	International Development Agency (IDA)
IFCGR	Indo-French Centre for Groundwater Research
IIT	Indian Institute of Technology
IMD	Indian Meteorological Department
IWRM	Integrated water resources management
LJS	Lucknow Municipal Water Utility
MB	Model bill (groundwater)
MEF	Ministry of Environment and Forests
MLD	Megaliters per day
NEP	National Environmental Policy
NIH	National Institute of Hydrology

NEERI	National Environmental Engineering Research Institute
NEP 2006	National Environment Policy
NGO	non-government organization
NGRI	National Geophysical Research Institute
NGTA 2010	National Green Tribunal Act
NWP	National Water Policy
PMB 2008	Pesticides Management Bill
PRA	Panchajat Raj Act
SGWA	State Groundwater Agency
SGWAC	State Groundwater Act
SGWDMA	State Groundwater Development and Management Agency
SGB	State Groundwater Board
SO	support organizations
SPCB	State Pollution Control Board
SWMR 2000	Solid Waste Management Rules
UN	United Nations
UP	Uttar Pradesh
WB	World Bank
WPCPA 1974	Water (Prevention and Control of Pollution) Act
WPCPCA 1977	Water (Prevention and Control of Pollution) Cess Act
WQAA	Water Quality Assessment Authority

GLOSSARY OF INDIAN TERMS

Gram panchayat	Elected village council
Kharif	Hot/wet season
Nahar	Water supply traditional source
Panchayat	Assembly of five wise respected leaders and accepted by village
Rabi	Cool/dry season
Mandals	Administrative district within Andhra Pradesh
Talukas	Administrative district in some states of India including Goa, Gujarat, Karnataka and Maharashtra

Note: Unless otherwise noted, all currency is in U.S. dollars.

ACKNOWLEDGMENTS

This report was prepared as a background paper for the World Bank Group's economic and sector analysis (ESW) entitled "Too big to fail: The Paradox of Groundwater Governance" prepared under the overall guidance of Rafik Hirji (team leader).[1] It was prepared by Hector Garduno, Saleem Romani, Babu Sengupta, Albert Tuinhof and Richard Davis. Its preparation benefitted from the support of GW-MATE and the Trust Fund for Environmentally and Socially Sustainable Development (TFESSD) made available by the governments of Finland and Norway. Overall, the main source of information is the World Bank report entitled "Deep Wells and Prudence: towards pragmatic action for addressing groundwater overexploitation in India," which was prepared after a five-year advisory analytical assistance study for the Government of India. Details at the local aquifer level are from GW-MATE's case profile collection, and boxes are from the more recent strategic overview series.

The Government of India decided that the India study should be focused on overexploitation (called intensive abstraction in this case study) issues, which have been increasing at an alarming rate in the last decades. Groundwater quality issues were thus only marginally addressed in connection with intensive exploitation. Sanjay Pahuja encouraged us to include the quality dimension.

The authors also wish to thank Amal Talbi (GW-MATE's interim manager during the last half of 2010) for his guidance during the preparation of this case study, as well as Anju Gaur and Marcus Wijnen from the World Bank for their exhaustive revision of and valuable input to the first draft.

[1] During the Project Concept Note review, the proposed title for this Economic and Sector Work was "Improving groundwater governance: The Political economy of groundwater policy and institutional reforms".

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DISCLAIMER

EXECUTIVE SUMMARY

Groundwater and socio-economic development

Groundwater has played a significant role in the maintenance of India's economy, environment, and standard of living. India is the largest groundwater user in the world. Through the construction of millions of private wells, there has been a phenomenal growth in the exploitation of groundwater in the last five decades. The factors driving this expansion include poor public irrigation and drinking water delivery, new pump technologies, the flexibility and timeliness of groundwater supply, and government electricity subsidies. As a result, 29 percent of the groundwater assessment blocks in the country are classified in semi-critical, critical, or overexploited categories with the situation deteriorating rapidly.

The government has no direct control over the groundwater use of millions of private well owners, both in rural and urban areas. In part, this is due to the absence of a systematic registering of wells with attached user rights and metering. In an indirect way, groundwater use is also sometimes limited through power shedding with limited hours of electricity supply, especially in rural areas.

The potential social and economic consequences of continued weak or nonexistent groundwater management are serious. Aquifer depletion is concentrated in many of the most populated and economically productive areas—and the consequences will be most severe for the poor. Furthermore, climate change will put additional stress on groundwater resources, while at the same time having an unpredictable impact on groundwater recharge and availability.

Widespread groundwater pollution could render the resource useless before it is exhausted. It also must be noted that indiscriminate abstraction of groundwater aggravates the quality problems, and thus a more integrated approach to the resource quality and quantity is needed.

A gradual approach is needed to improve groundwater management within the existing institutional framework and available information. Demonstrating successful interventions at the local level is very much in line both with the India Planning Commission Groundwater Expert Group conclusions of 2007 and the recommendations of the 2010 International Workshop on Groundwater Protection held in New Delhi. The balance of the management measures selected and the management instruments utilized will depend upon a diagnosis of the resource setting, which in essence both define the problem and shape the solution.

Case study aquifers and intensive groundwater abstraction

World Bank (WB) assistance has focused on pilot projects in areas with both rural and urban land uses in both hard-rock terrain in peninsular India and the major alluvial formations in the rural Indo-Gangetic Plains. Both regions face the issue of intensive groundwater abstraction. Eight pilot aquifers are the foundation for discussing groundwater governance at the local level in this report**.** They comprise the following types:

- Aquifers subject to intensive abstraction in hard-rock rural areas: (a) weathered zone of the Deccan Traps Basalt underlying Maharashtra and in Andhra Pradesh; (b) low-storage variably weathered crystalline basement aquifer underlying most of drought-prone Tamil Nadu state; and (c) elevated alluvial areas of the Indo-Gangetic Peneplain of central Punjab state with relatively deep water tables.
- An aquifer subject to intensive abstraction in a hard-rock urban area: (a) Deccan Traps basalt lava flows, with groundwater confined to the weathered horizon, underlying Aurangabad in the drought-prone interior of Maharashtra state.
- Aquifers subject to intensive exploitation in the alluvial tracts of the Ganges Valley: (a) aquifer system of layered sand-silt deposits in the rural area of Uttar Pradesh state; and (b) large thickness of Quaternary alluvial sands with "three productive horizons" underlying Lucknow City in Uttar Pradesh state.

Groundwater quality and pollution

The groundwater quality dimension is addressed by describing pollution sources, namely (a) groundwater salinity (inland and coastal), (b) geogenic contaminants (arsenic, fluoride, and iron), and (b) anthropogenic contaminants from mining, industrial, tanneries, land-fills and garbage dumps, agriculture, and poor sanitation and wastewater disposal. The report highlights the need for groundwater quality management if groundwater use is to be sustainable.

Groundwater governance framework

The main findings related to groundwater governance are:

- Even though the 1998 National Water Policy (NWP) and the 2002 amended version do not have statutory status, and thus cannot be legally enforced, they are the outcome of intensive political discussions and so state governments could find them useful in developing their own water policies. Agriculture, energy, water supply, and many other sectoral policies influence groundwater use and pollution, but they are difficult to reform.
- The legal system for groundwater management in India falls within a complex, multilayered framework of constitutional and statutory provisions at the central and state levels. It is clear that groundwater management falls under the jurisdiction of the states and to this effect the central government has circulated since 1970 a model groundwater bill. Regretfully, only a few states have formally adopted it. Nevertheless, the two main legal drawbacks (the resource being assumed to follow the right to land and the absence of groundwater legislation at the central level) have been sorted out by:
  - The Supreme Court and High Court rulings have affirmed the government's right and obligation to protect groundwater under the right to life guaranteed by the Constitution
  - The Planning Commission's Groundwater Expert Group have argued that the legislative framework is reasonably robust for effective groundwater management, so the priority lies in enforcement of existing measures, supported by innovative approaches such as an expansion of community based-management.
- The Central Groundwater Authority (CGWA) and the Central Groundwater Board (CGB) (supported by State Groundwater Boards, or SGBs) are the primary agencies for groundwater management. Albeit having the potential to become champions of sustainable groundwater

management the CGWA, CGB, and SGBs are severely handicapped by their chronic understaffing and lack of coordination with a large number of other government agencies impacting the resource.

- The legal and institutional framework for groundwater protection is also complex. The Water (Prevention and Control of Pollution) Act of 1974 and the Environmental (Protection) Act of 1986 deal with most pollution issues in India, but there are thirteen other related policy and legal ordinances. The Central Pollution Control Board (CPCB)—and at the state level the SGWAs and SPCBs—are the main responsible agencies, but fourteen other organizations also play a role. Within this framework, enforcement is not easy and state agencies are not well-equipped.
- Institutional technical capacity at the national and state levels is generally weak, but there is a core base of high-level professionals and the knowledge base and potential of research organizations, government institutions and universities is well-developed. A key recommendation is to conduct a national conference to strengthen the links between practice and research and graduate studies.
- Given the millions of water wells in India—mainly drilled, operated, and maintained by private users—and the scant institutional enforcement capacity, we cannot currently expect users to contribute toward groundwater management costs. There is, however, an outstanding issue that merits discussion: the “groundwater-energy nexus” and one possible way forward through up-scaling Gujarat’s promising Jyotigram Scheme.

Lessons Learned

The main lessons learned from the pilot aquifers are:

- Up-scaling and replication of very positive community-based groundwater management experiences will necessitate a flexible phased approach together with development of a “lighthouse function” in the state government. This is to ensure that pilot initiatives do not fail because of lack of support and control, especially after government or donor agency support finishes and to make sure that experiences from successful interventions can be up-scaled and remain available for replication.
- Policies must be developed to improve urban groundwater finances and groundwater quality if the widespread institutional vacuum in Indian urban groundwater is to be addressed.
- In the Indo-Gangetic Plain, changes in management practices such as postponing transplanting paddy rice to achieve “real groundwater savings” can help conserve groundwater.

One key conclusion from this assessment of groundwater quality management and pollution control is that although the complex legal and institutional framework is generally satisfactory, the implementation capacity is largely ineffective. Lessons learned from the examples include (a) the need for raising awareness of professionals and decision makers; (b) when good communication exists between researchers and decision makers, relevant groundwater quality problems can be solved; (c) the uncertainty of the economic viability vis à vis environmental sustainability of implementing technological advancements highlights the need to understand the true value of the groundwater resources and promote some economic incentives; (d) effective communication can enable community participation; and (f) stakeholder participation can effectively contribute to decentralized water quality protection.

Climate Change

In both rural and urban environments, the lessons learned in pilot aquifers in the Indo-Gangetic Plain show that it is worthwhile to move from spontaneous or incidental to more planned conjunctive use. This is useful for coping with climate change and for reducing waterlogging as well as inland and coastal salinization and other groundwater quality threats. At the same time, it is important to promote better characterization of underlying aquifers, institutional strengthening and coordination, and improved awareness among farmers and municipal engineers.

No matter how merit-worthy groundwater recharge enhancement measures may be—and their potential as a tool for adaptation to climate change—the question of the extent to which such measures benefit the sustainability of specific rural water supply sources has to be addressed.

Recommendations

Recommendations for addressing groundwater over-abstraction include (a) using a mixture of management approaches, and (b) a balanced set of on-the-ground actions. But these actions must be implemented within existing provisions and institutional capacity, given the fact that the technical, legal, and institutional provisions are in a more or less acceptable status but the implementation capacity is weak. An overriding conclusion for all pilot projects is thus that the weakest link of all the elements in the groundwater governance chain is institutional capacity—and that although some degree of community self-regulation is required, government capacity to enable and nurture it must be strengthened.

In many cases, groundwater pollution is caused or aggravated by intensive groundwater abstractions. This is the case for seawater intrusion in coastal aquifers, but also for various types of geogenic pollution such as high fluoride and arsenic levels. In these cases, groundwater quality has to be considered when establishing safe groundwater abstraction levels and management practices. The required legal and institutional provisions for most cases are acceptable, but the level of implementation capacity is lacking. Nevertheless, much can be learned from both unsuccessful and successful cases, including (a) the need to raise awareness among professionals and decision makers and develop effective communication with stakeholders; (b) the use of sophisticated mathematical models coupled with adequate experimental data to help remediate contaminated aquifers; (c) the value of adequately costing groundwater resources and environmental benefits; and (d) the use of innovative solutions, such as using distillery effluents to grow commercial plantations.

The main recommendation for improving groundwater management in India is strengthening the State Groundwater Development and Management Agencies (SGWDMAs). A broad outline is presented of how they could be reorganized. However, successful implementation also depends on (a) political commitment at the highest level; (b) acknowledging the need for a transition to a substantially less water-demanding economy in some critical blocks to reduce the risk of permanent deterioration; and (c) acknowledging the fact that SGWDMAs are imbedded within a macro political and economic system and therefore an open dialogue with the central level must be established to reduce bureaucratic restrictions and grant the required support to state agencies to become groundwater resource guardians.

In dealing with intensive exploitation in aquifers, it would be advisable to start with pilot projects in prevention and control for different pollution sources under different aquifer typologies in parallel with institutional strengthening.

1. INTRODUCTION AND BACKGROUND

1.1. Case study background

The World Bank with the support of various partners is undertaking an economic and sector analysis (ESW)—entitled “Too Big to Fail: The Paradox of Groundwater Governance”—to understand the impediments to better groundwater governance, and to identify the opportunities for ensuring that groundwater becomes a key element of integrated water resources management (IWRM) in developing countries. The recommendations from the ESW will guide the Bank in its investments on groundwater and provide contributions to a GEF-funded global project—“Groundwater Governance: A Framework for Country Action”—to be led by FAO and supported by UN water agencies and other partners.

Five countries—India, Kenya, Morocco, South Africa, and Tanzania—were selected by the WB as case studies. Each case study reviews and identifies the nature and characteristics of specified groundwater resources; its use in rural and urban water supply, industry and irrigation; emerging issues and the best practices; threats; and knowledge gaps regarding good groundwater governance. The objectives of the case studies were to (a) describe the groundwater resource characteristics for selected aquifers, including groundwater use patterns, user profiles, and socioeconomic factors influencing the use; (b) describe the governance arrangements for managing groundwater; (c) describe the implementation of these governance arrangements in the specific aquifers, and (d) identify the relevance of these arrangements for strategies to cope with climate change impacts.

1.2. Groundwater governance

In this study, groundwater governance refers to those political, social, economic, and administrative systems that are explicitly aimed at developing and managing water resources and water services at different levels of society that rely solely or largely on groundwater resources. This definition includes all related mechanisms including financing, knowledge, and technical capacity, and the rights and responsibilities of sector players (including water users). “Bad governance” includes any of the following activities, attitudes, or approaches to groundwater resources management: (a) inadequate policies, strategies, and legislation relating to groundwater resources and their management, or the ineffective application of those policies, strategies, or legislation; (b) inadequate technical and financial capacity to support groundwater resources management; (c) lack of professional integrity, transparency, and accountability; (d) failure to enforce laws relating to allocation and groundwater use; (e) ignoring stakeholders’ rights to equitable access to groundwater resources; (f) poorly managed groundwater projects; and (g) inherent corruption in groundwater management processes, including “quiet corruption”—low-level, small-scale corruption at the service provider/ water user interface.

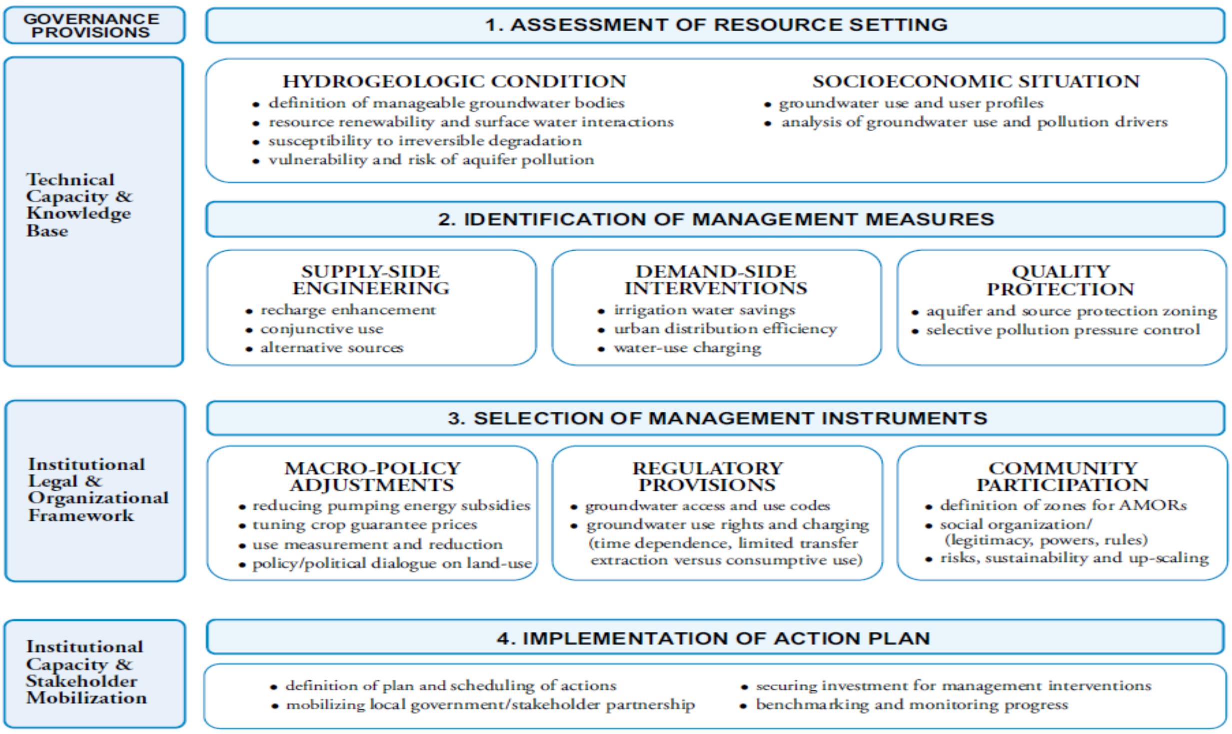
1.3. Methodology

Concerns about the growing crisis of aquifer depletion prompted the Planning Commission of India (Planning Commission 2007) to constitute an expert group to review the issue of groundwater management and suggest appropriate and pragmatic policy directions. In this context, World Bank assistance—instead of proposing high-level legal and policy reforms—focused on the pursuit of pragmatic approaches that could make incremental improvements largely within the existing institutional framework, building political support for gradual and realistic institutional improvements at higher levels by first demonstrating successful interventions at the local/pilot level.

There is also an urgent need for groundwater quality management. These problems require scientific understanding of hydrogeological controls for naturally occurring minerals in the aquifers and the prevailing conditions. At the same time, pragmatic and urgent measures—similar to the expert groundwater group approach mentioned above and the recommendations from the International Workshop on Groundwater Protection (see Annex 1)—must be taken gradually with the available information and within the existing institutional framework.

Management measures to address intensive abstraction problems can be classified in terms of supply-side engineering and demand-side interventions, and the management instruments as macro-policy adjustments, regulatory provisions, and community participation and education (Figure 1). On the other hand, groundwater protection (GW-MATE 2002a) requires aquifer and source protection zoning and/or selective pollution pressure control. Usually multiple measures or instruments will be required at the local level, as illustrated in the case study aquifers.

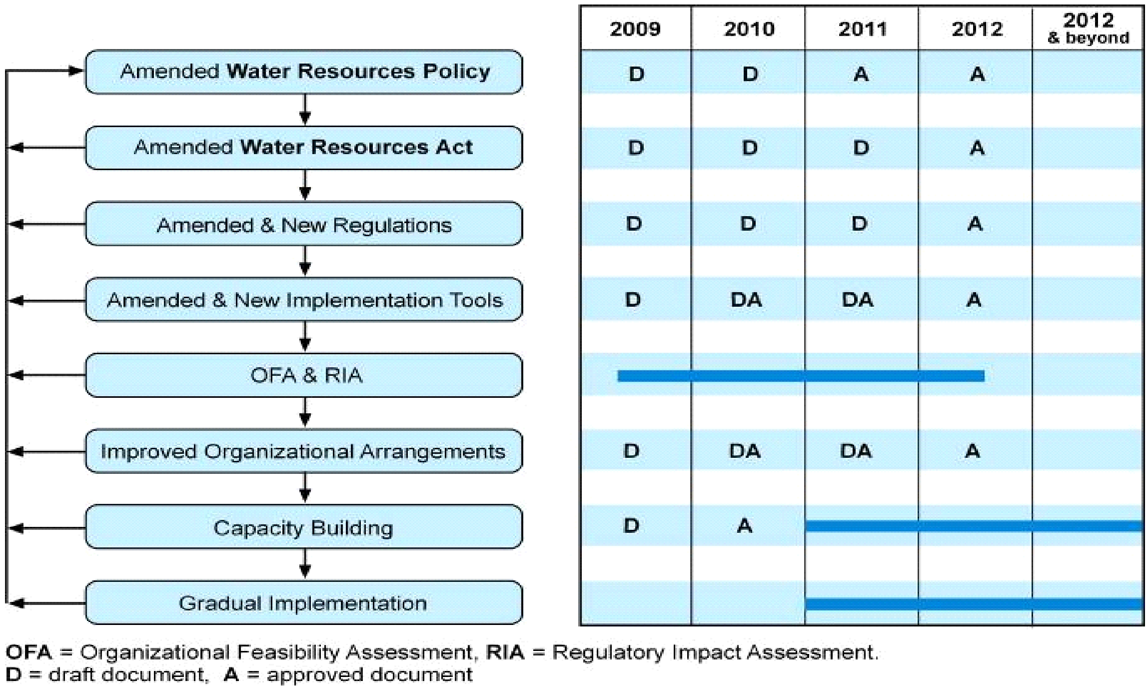
Figure 1: Pragmatic framework for elaboration of a GW management action plan



Source: GW-MATE, 2010a.

The cautious approach recommended by the Groundwater Expert Group of the Planning Commission and followed by the WB in its assistance to India has also been one of the key lessons learned by GW-MATE. It is termed the “parallel track approach” (Figure 2). The time frame used in this figure is only indicative. Nevertheless, it is meant to stress the need for very long processes for institutional strengthening.

Figure 2: The "Parallel Track Approach" to facilitate implementation



Source: Garduño 2001

1.4. Report structure

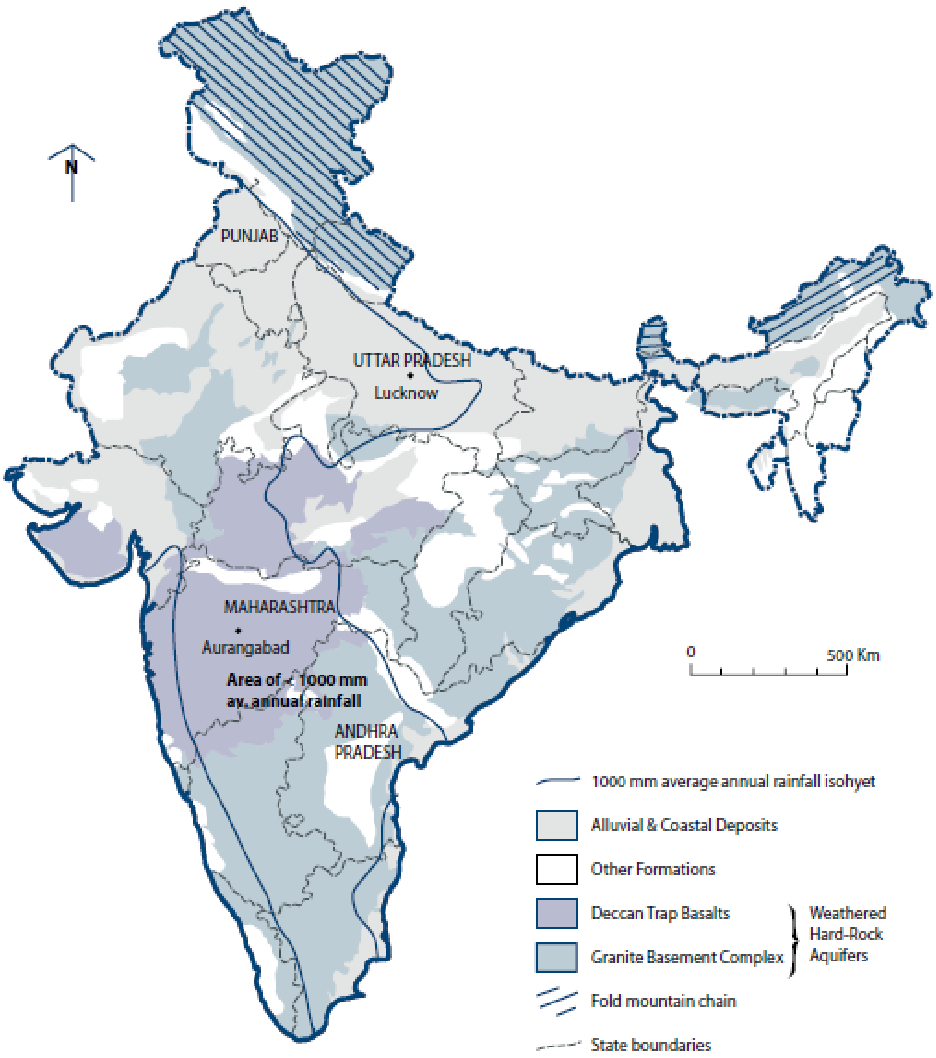
This Indian case study report is largely based on (a) the findings and recommendations of the recently published India study "Deep Wells and Prudence: Towards Pragmatic Action for Addressing Groundwater Overexploitation in India" focused mainly on aquifer intensive abstraction groundwater issues (World Bank 2010); (b) a number of GW-MATE case profile and strategic overview series publications, which addressed in more detail the local level in seven rural and urban aquifers; and (c) reports on groundwater quality-related aspects prepared by two local consultants aimed at addressing the technical/managerial and legal/institutional dimensions of aquifer protection in the country.

2. RESOURCE SETTING: OVEREXPLOITATION AND GROUNDWATER POLLUTION

2.1. Hydro geologic and socioeconomic features at the national level

While groundwater resource availability is determined by the physical environment, the dynamics of groundwater use are determined by the socioeconomic environment—that is, the nature of economic activity, patterns of population density, and societal norms that influence attitudes towards groundwater use—and the institutional environment, including the legal, administrative, macroeconomic, and political dimensions. It is this range of factors that will ultimately determine the sustainability of the resource. They are fully considered in the methodology of this case study.

Figure 3: Main Hydro geological provinces of India



Source: WB 2010: Fig. 2.3.

The physical characteristics of the groundwater resources can vary considerably. Within India there are two broad types of hydrogeological settings: (1) the shallow, low-storage hard-rock aquifers occurring in the basaltic and granitic systems of peninsular India; and (2) the large, high-storage sedimentary aquifers that underlie the Indo-Gangetic floodplains of northern India and part of the coastal areas (Figure 3 and Table 1).

Table 1: Main groundwater settings in selected states in India

STATE	Approximate area (%) Weathered Hard-Rock Deccan Trap Basalts	Aquifers Granite Basement Complex	Sum	Alluvial & Coastal/Flood Plains	Other Formations
Andhra Pradesh	3	65	68	14	18
Gujarat	30	7	37	52	10
Haryana	0	2	0	98	0
Karnataka	7	90	97	2	1
Kerala	0	75	75	25	0
Maharashtra	77	15	92	5	3
Madhya Pradesh	49	12	61	15	24
Punjab	0	0	0	97	3
Rajasthan	5	25	30	55	15
Tamil Nadu	0	73	73	22	5
Uttar Pradesh	0	20	20	70	10

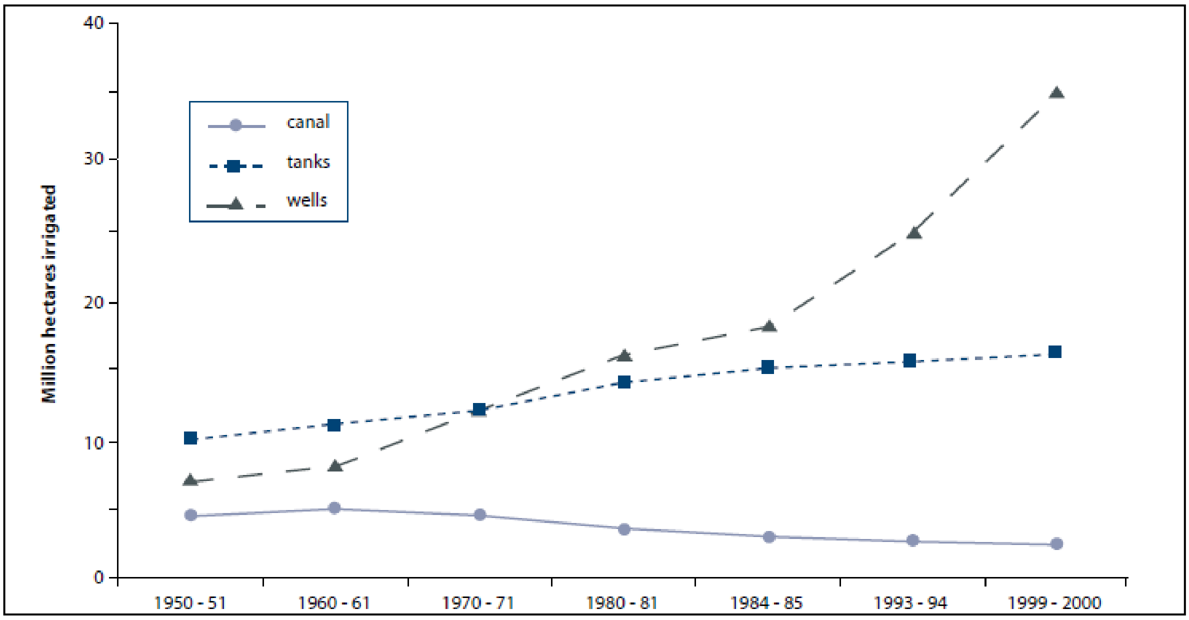
Source: WB 2010: Sec2:15 (Estimates based on CGWB 2006).

Superimposed on this is a complex of socioeconomic factors (Table 2) that determine the dynamics of groundwater extraction, such as the distinction between rural and urban use; the relative inadequacy of public water supply systems; the size of landholdings and the related density of water wells; the political ramifications of subsidized power for irrigation pumping; and the institutional capacity to monitor and regulate the millions of wells.

2.2. Groundwater overabstraction

India is the largest groundwater user in the world, with an estimated usage of around 230 km^3 per year, more than a quarter of the global total. With more than 60 percent of irrigated agriculture and 85 percent of drinking water supplies dependent on it, groundwater is a vital resource for rural areas in India. Reliance of urban and industrial water supplies on groundwater is also becoming increasingly significant in India. Through the construction of millions of private wells, there has been a phenomenal growth (Figure 4) in the exploitation of groundwater in the last five decades.

Figure 4: Evolution of canal, tank, and well irrigation in India, 1950–2000



Source: Bhatia 2005.

A number of factors have encouraged the remarkable expansion of groundwater use, including (a) poor service delivery from public water supply systems has prompted many farmers, and rural and urban households, to turn to their own private supply for irrigation and for drinking water; (b) new pump technologies and credit facilities meant that even farmers and households with very modest incomes could afford to sink and operate their own tubewells; (c) the flexibility and timeliness of groundwater presented an attractive alternative to the technically and institutionally less responsive provision of surface water through public systems; and (d) government electricity subsidies that have shielded farmers from the full cost of pumping, creating a modality of groundwater use that has proved very difficult to change.

This era of seemingly endless reliance on groundwater for both drinking water and irrigation purposes is now approaching its limit as an increasing number of aquifers reach unsustainable levels of exploitation. A 2004 nationwide assessment (Table 3) found 29 percent of groundwater blocks to be in the semi-critical, critical, or overexploited categories, with the situation deteriorating rapidly. Currently the CGWB is updating this assessment for 2008–09.

The term “aquifer overexploitation” is not capable of rigorous scientific definition (GWMATE 2002b) because of the sheer complexity of physical, environmental, socioeconomic, and other factors related to groundwater abstraction. Thus a preferred term for a physically unsustainable situation in which the abstraction of groundwater exceeds replenishment is intensive groundwater abstraction.

Table 2: Groundwater resource and socioeconomic aspects in selected states

State	Groundwater resource status					Socioeconomic status		Socioeconomic drivers for groundwater demand and pollution								
								Drinking water	Irrigated agriculture						Industries	
	In-storage groundwater resource (cubic kilometers) (alluvium, hard rocks)	Net annual groundwater availability (cubic kilometers)	Annual use (cubic kilometers)	Groundwater development (%)	Critical and overexploited units (%)	Per capita income as percent of all India average	Poverty index (% of population)	Population density as percent of all India average	Gross irrigated area (million hectares)	Marginal to medium landholdings (% of landholdings < 10 hectares)	Large landholdings (% of landholdings > 10 hectares)	High-water-demanding (rice, wheat, sugar cane) (% of gross area)	Irrigated with groundwater (% of gross area)	Power consumption (gigawatt hours/cubic kilometer)	High-water-demanding industries	Number of wells (million), as at March 2006
Andhra Pradesh	10	33	15	45	24	92	16	84	5	92	8	66	39	1,131	Low	1.92
Gujarat	10	15	12	76	19	114	17	83	4	89	11	29	63	1,160	High	0.78
Haryana	42	9	10	109	66	129	14	146	5	77	23	65	29	696	High	0.47
Karnataka	2	15	11	70	68	84	25	84	3	89	11	37	34	1,024	High	1.36
Kerala	1	6	3	47	13	114	15	82	04	93	7	40	28	128	Low	0.44
Madhya Pradesh	4	35	17	48	9	54	38	60	6	84	16	86	64	388	Low	2.77
Maharashtra	4	31	15	48	2	125	31	96	4	93	7	36	50	804	High	2.45
Punjab	91	21	31	145	79	124	8	147	8	73	27	79	40	276	Low	0.75
Rajasthan	13	10	13	125	80	66	22	50	7	60	40	33	60	520	Low	0.63
Tamil Nadu	10	21	18	85	46	105	23	146	2	93	7	56	52	610	High	1.66
Uttar Pradesh	350	70	49	70	7	46	33	102	18	97	3	82	52	513	High	2.61
All India	**1,081**	**399**	**230**	**58**	**19**	**100**	**28**	**100**	**55**	**87**	**13**	**28**	**48**	**524**		**19.59**

Source: WB 2010: Table 2.2.

It is important to stress that, even though the systematic and annual exercise of assessing the groundwater balance within the nearly 6,000 groundwater blocks has been an essential tool in mapping groundwater conditions in India and creating awareness among decision makers, the exercise has some major limitations. The units used for the groundwater assessment exercise are administrative units, mostly at the sub district level, without any link to physical boundaries.

Table 3: Groundwater categorization of blocks/mandals/talukas in India

Sl. No.	States / Union Territories	Total No. of Assessed Units	Safe		Semi-critical		Critical		Over-exploited		Remarks
			Nos.	%	Nos.	%	Nos.	%	Nos.	%	
	States										
1	Andhra Pradesh	1231	760	62	175	14	77	6	219	18	-
2	Arunachal Pradesh	13	13	100	0	0	0	0	0	0	-
3	Assam	23	23	100	0	0	0	0	0	0	-
4	Bihar	515	515	100	0	0	0	0	0	0	-
5	Chattisgarh	146	138	95	8	5	0	0	0	0	-
6	Delhi	9	2	22	0	0	0	0	7	78	-
7	Goa	11	11	100	0	0	0	0	0	0	-
8	Gujarat	223	97	43	69	31	12	5	31	14	Rest 14 talukas- Saline
9	Haryana	113	42	37	5	4	11	10	55	49	-
10	Himachal Pradesh	5	5	100	0	0	0	0	0	0	-
11	Jammu & Kashmir	8	8	100	0	0	0	0	0	0	-
12	Jharkhand	208	208	100	0	0	0	0	0	0	-
13	Karnataka	175	93	53	14	8	3	2	65	37	-
14	Kerala	151	101	67	30	20	15	10	5	3	-
15	Madhya Pradesh	312	264	85	19	6	5	2	24	8	-
16	Maharashtra	318	287	90	23	7	1	0	7	2	-
17	Manipur	7	7	100	0	0	0	0	0	0	-
18	Meghalaya	7	7	100	0	0	0	0	0	0	-
19	Mizoram	22	22	100	0	0	0	0	0	0	-
20	Nagaland	7	7	100	0	0	0	0	0	0	-
21	Orissa	314	308	98	0	0	0	0	0	0	Rest 6 blocks- Saline
22	Punjab	137	25	18	4	3	5	4	103	75	-
23	Rajasthan	237	32	14	14	6	50	21	140	59	Rest 1 block- Saline
24	Sikkim	1	1	100	0	0	0	0	0	0	-
25	Tamil Nadu	385	145	38	57	15	33	9	142	37	Rest 8 blocks- Saline
26	Tripura	38	38	100	0	0	0	0	0	0	-
27	Uttar Pradesh	803	665	83	88	11	13	2	37	5	-
28	Uttaranchal	17	12	71	3	18	0	0	2	12	-
29	West Bengal	269	231	86	37	14	1	0	0	0	-
	Total States	**5705**	**4067**	**71**	**546**	**10**	**226**	**4**	**837**	**15**	**-**
	Union Territories										
1	Andaman & Nicobar	1	1	100	0	0	0	0	0	0	-
2	Chandigarh	1	1	100	0	0	0	0	0	0	-
3	Dadra & Nagar Haveli	1	1	100	0	0	0	0	0	0	-
4	Daman & Diu	2	0	0	1	50	0	0	1	50	-
5	Lakshdweep	9	6	67	3	33	0	0	0	0	-
6	Pondicherry	4	2	50	0	0	0	0	1	25	Rest 1 Region- Saline
	Total Uts	**18**	**11**	**61**	**4**	**22**	**0**	**0**	**2**	**11**	**-**
	Grand Total	**5723**	**4078**	**71**	**550**	**10**	**226**	**4**	**839**	**15**	**-**

Note

Blocks- Bihar, Chhattisgarh, Haryana, Jharkhand, Kerala, Madhya Pradesh, Manipur, Mizoram, Orissa, Punjab, Rajasthan, Tamilnadu, Tripura, Uttar Pradesh, Uttaranchal , West Bengal
Mandals (command/ non-command) - Andhra Pradesh
Talukas - Goa, Gujarat, Karnataka, Maharashtra
Districts - Arunachal Pradesh, Assam, Delhi, Meghalaya, Nagaland
Districts (Valley) - Himachal Pradesh, Jammu & Kashmir
State - Sikkim
Islands - Lakshdweep
UT - Andaman & Nicobar, Chandigarh, Dadra & Nagar Haveli,Daman & Diu, Pondicherry

Source: CGWB http://cgwb.gov.in/documents/Categorzation_statewise.pdf (consulted on January 28, 2011)

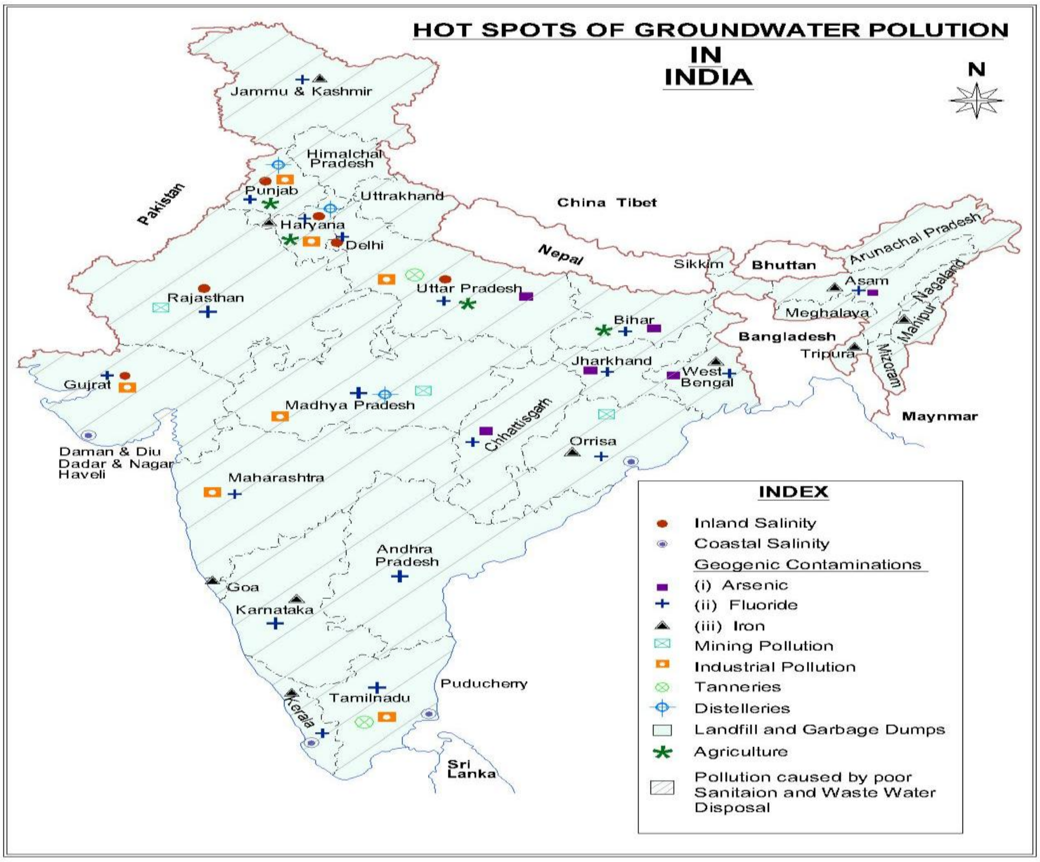
Depending on the administrative unit chosen, average block sizes vary from 300 km^2 to more than 1,000 km^2 in the major states. Hydrogeological conditions and groundwater use may vary considerably within a block, and blocks that are marked as “safe” or “semi-critical” may contain critical areas.

The method uses an accounting approach to establish block water balances that does not reflect the dynamic relationships within a natural groundwater system, especially in the case of multiple aquifers. Therefore, when addressing groundwater-intensive exploitation in a specific case or region, the resource assessment should be based on an understanding of the dynamic groundwater system within its natural boundaries.

2.3. Characterization of groundwater pollution

Notwithstanding the need to prioritize the issue of aquifer depletion, in an increasing number of regions in India (Figure 5) groundwater pollution could render the resource useless before it is exhausted. In addition to the anthropogenic pollution of groundwater, the contamination due to geogenic sources—such as arsenic, fluoride, and iron—as well as salinity problems in coastal and inland areas are the major quality issues in India.

Figure 5: Hot-spot states of groundwater pollution in India



Source: Romani 2006: Fig. 2.

Table 4 shows the territorial coverage of the different pollution sources, which are briefly described below.

2.3.1. Inland groundwater salinity

This is the single most challenging problem in the arid and semi-arid regions of Rajasthan, Haryana, Punjab, and Gujarat and with limited extent in other states. The soluble salts from weathering of rocks tend to accumulate in the soils. During the rainy season, these salts are leached from the soil to the saturated zone. Due to low rainfall and high evaporation in these regions, the groundwater circulation is slow, resulting in high salinity. Inland salinity is also caused by faulty surface water irrigation practices from dams without much consideration of the status of the local groundwater along unlined canals.

Table 4: Pollution hot spots in Indian states

	HOT-SPOT STATES																						
	Andhra Pradesh	Assam	Bihar	Chattisgarh	Delhi	Goa	Gujarat	Haryana	Jammu & Kashmir	Jharkhand	Karnataka	Kerala	Madya Pradesh	Maharashtra	Manipur	Meghalaya	Orissa	Punjab	Rajasthan	Tamil Nadu	Tripura	Uttar Pradesh	West Bengal
INLAND SALINITY																							
Inherent Salinity					P		W	W			P		P	P				W	W	P		P	
Water Logging Under Surface Irrigated Areas								W										W				W	
COASTAL SALINITY																							
Saline Ingress from tides, cyclones & tsunamis							W					W					W						
Sea Water Intrusion							W													W			
GEOGENIC																							
Arsenic		P	P	P						P												P	W
Fluoride	W	P	P	W	P		W	W	P	P	W	P	P	P			P	W	W	W		P	P
Iron	W	W	P	P		W	P	W	W	P	W	W	P	P	P	P	W	P	W	P	W	P	W
ANTHROPOGENIC																							
Mining													W	W			W		W				
Industrial							W	W					W	W				W		W		W	
Tanneries																				W		P	
Distilleries								W					W					W					
Landfill & Garbage Dumps	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Agriculture			W					W										W				W	
Poor Sanitation & Wastewater Disposal	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
P - partial coverage																							
W - widespread																							

Source: Romani 2010: Annexure 1.

2.3.2. Coastal salinity

The Indian subcontinent has a dynamic coastline that is about 7,500 km long. Saltwater can invade the coastal aquifers either laterally from the coastline or upcone from deeper layers, when groundwater levels in coastal aquifers drop to close to sea level. If there are tidal rivers or estuaries overlying the aquifer, then saltwater can also infiltrate from the surface. Once an aquifer is contaminated by saltwater, there is a long-term loss of freshwater storage capacity because the process can take decades to be reversed. Evidence of seawater intrusion has been observed in several states, including in Tamil Nadu, Pondicherry and Saurashtra in Gujarat.

2.3.3. Geogenic contamination

Hydrogeology plays an important role in controlling the quality of groundwater. The concentration of minerals in the rock matrix, the nature of the depositional history, and subsequent changes in geochemical conditions cause minerals to mobilize in groundwater. In India, the major type of geogenic contamination of groundwater is from arsenic and fluoride. This affects the health of a large proportion of the population. Iron is another contaminant of geogenic source, but is a lesser health hazard.

The occurrence of high concentrations of arsenic in groundwater was first reported in 1980 from West Bengal, where a population of more than 5 million in eight districts was affected by high arsenic content in drinking water (exceeding permissible limit of 0.05 mg/l). Recent exploration shows that drinking water sources of some other areas in the Ganga Basin—covering parts of UP, Bihar, and Jharkhand—are also contaminated.

High fluoride concentrations in groundwater (beyond the permissible limit of 1.5 mg/l) are also a major public health problem in India. Nearly 90 percent of the rural population of the country use groundwater for drinking and domestic purposes. With 196 districts in 19 States of India identified with the problem of excess of fluoride in groundwater, a huge rural population is threatened with the serious health hazard of fluorosis.

Iron in natural waters is an essential constituent in both plant and animal metabolism. Abnormally large amounts (exceeding 1 mg/l) may result in cirrhosis, with suspected diarrheal and cardiac linkages. In a large number of areas—in West Bengal, Rajasthan, Orissa, Goa, Haryana, Jammu and Kashmir, Andhra Pradesh, Karnataka, and Kerala—the groundwater is highly contaminated with iron.

2.3.4. Groundwater pollution threats from anthropogenic activities

The most widespread problem of anthropogenic pollution in India is the contamination of aquifers due the fast pace of urbanization, coupled with poor sanitation in rural areas. The former causes acute concentrated pollution and the latter widespread contamination. The state of sanitation is so poor that two out of every three Indians defecates in the open, more due to constraint than behavior. The sanitation coverage is 47 percent for rural populations and 83.2 percent for urban areas (Khurana et al. 2009).

Urban centers contribute more than 25 percent of the sewage generation in the country. According to the CPCB report of 2009, wastewater generation in the 498 Class I cities (population exceeding 100,000) is 35,558 MLD, of which only 30 percent is treated. In Class II towns (population 50,000 to 100,000), only 8 percent of total wastewater generation of 2,697 MLD is treated. Untreated wastewater ultimately reaches rivers, lakes, ponds and creeks. A large proportion of wastewater generated in urban areas contaminates aquifers underlying these cities. As a result, most urban aquifers show high nitrate levels, often exceeding the drinking water standard.

Agricultural activities are another major source of fertilizers, pesticides, animal wastes, and crop wastes which pollute aquifers. High levels of nitrate and potassium in groundwater in several parts of the country are ascribed to an excessive application of fertilizers. The use of nitrogenous fertilizers has increased nearly 100-fold from only 35,000 tons in 1947-48, and is the main source of high nitrate in groundwater. Pesticides which are bio-accumulative and relatively stable as well as toxic or carcinogenic are another threat to groundwater.

Other sources of pollution arise from economic activities such as mining, industry, tanneries and distilleries, landfills & garbage dumps, and, more recently, disposal of e-waste.

3. THE GOVERNANCE FRAMEWORK

3.1. Policy and legal framework for groundwater management

3.1.1. National Water Policy

The main policies affecting groundwater management are the 1998 National Water Policy (NWP) and the 2002 amended version. Both have no statutory status, and thus cannot be legally enforced. They are the outcome of intensive political discussions. State governments could find them useful in developing their own water policies by adapting them to their specific agro-climatic and socioeconomic characteristics leading to the implementation of the Expert Group recommendations:

- Water resources should be managed in the context of the environment, ecology, sustainability, equity, social justice, conservation, participation of stakeholders, and role of women.
- There should be a periodical reassessment of the groundwater potential on a scientific basis, taking into consideration the quality of the water available and economic viability of its extraction.
- The abstraction of groundwater resources should be regulated so as not to exceed the safe yield while ensuring social equity.
- The detrimental environmental consequences of over-abstraction of groundwater need to be prevented by the central and state governments.
- Groundwater recharge projects should be developed and implemented for improving both the quality and availability of groundwater resources.
- Integrated and coordinated development of surface water and groundwater resources and their conjunctive use should be considered from the project planning stage, and should form an integral part of project implementation.
- Over-abstraction of groundwater should be avoided, especially near the coast, to prevent ingress of seawater into freshwater aquifers.
- Both surface water and groundwater should be regularly monitored for quality.
- A phased program should be undertaken for improvements in water quality.
- For effective and economical management of India's water resources, there needs to be considerable improvement in knowledge by intensifying research efforts in various areas.

3.1.2. Legal framework

Groundwater in the Indian legal system falls within a complex, multilayered framework, consisting of a range of constitutional and statutory provisions at the central and state levels.

The right to groundwater has traditionally been seen as following the right to land, based on the Indian Easements Act of 1882. However, this long-established "real property" groundwater right is challenged by the emerging public interest dimension of groundwater use. In 1996, the Supreme Court, ruling under the Environment (Protection) Act (1986), instructed the government of India to establish the Central Groundwater Authority (CGWA) to regulate and control groundwater development with a view to preserving and protecting this resource. The decisions made in a more recent case involving the Coca-Cola Company also affirm the government's right and obligation to protect groundwater under the right to life guaranteed by the Constitution of India.

The Constitution lists "water supplies"—which is understood to include groundwater—under the state List, thereby giving the states jurisdiction to regulate and control groundwater. However, the central government also has a concurrent power to make laws with respect to any matter for any part of the territory of India. Accordingly, the central government has sought to support states in a pragmatic way through the issuance of the Model Groundwater Bill.

3.1.3. Model Groundwater Bill

The rationale for the bill is to provide a template for consideration by state governments, which can modify and adopt it according to their needs. It was first developed in 1970 and has subsequently been revised and circulated many times. Among other things, the bill recommends the establishment and empowerment of some form of "state groundwater management agency," and registration and control of at least the larger groundwater users. It is important to note that only a handful of states have enacted groundwater legislation based on the bill (Table 5).

Table 5: Comparison of the GW Model Bill and selected state adaptations enacted or in process

COMPONENTS ACCORDING TO INTERNATIONAL PRACTICE	MB	Andhra Pradesh	Maharashtra	Uttar Pradesh	Punjab	Tamil Nadu
GW PROPERTY						
PLANNING & MANAGEMENT						
WATER RIGHTS SYSTEM						
GW CONSERVATION & PROTECTION MEASURES						
INST. ARRANGEMENTS & STAKEHOLDER PARTICIPATION						
INFORMATION SYSTEMS						
ECONOMIC INSTRUMENTS						
GENERAL IMPLEMENTATION PROVISIONS						

MB (Groundwater) Model Bill

Degree of completeness compared to international practice	**high to medium**	

3.1.4. Conclusions

The Planning Commission's Expert Group on Groundwater Management and Ownership has argued that the legislative framework is reasonably robust since, in principle, it enables the groundwater management practices that are likely to be pragmatic and effective in India. Recent Supreme Court and State High Court rulings support the principle that private extraction rights can, and should, be curbed by the state if the use of groundwater is considered excessive. The Expert Group has therefore concluded that “no change in basic legal regime relating to groundwater seems necessary” (Planning Commission 2007) and that the priority lies in enforcement of existing measures, supported by innovative approaches such as an expansion of community-based management.

3.2. Policy and legal framework for groundwater protection

The Water (Prevention and Control of Pollution) Act of 1974 was the first national legislation designed to abate the pollution of this vital resource, legally establishing both central and state regulatory bodies. In addition, there are fourteen other policy and legal provisions related to groundwater protection (Annex 2).

Table 6 shows the list of all the policy and legal ordinances related to groundwater quality control, highlighting those most relevant to the pollution issues identified in hot-spot states.

Statistics regarding enforcement and compliance with pollution control ordinances for the seventeen categories of highly polluting industries show that, out of the largest 2,526 plants, 18 percent have been closed, 10 percent are defaulting, and 71 percent are complying isofar as they have installed pollution controlled equipment. On the other hand, control of pollution from the 3–3.5 million small- and medium-scale industries is less effective and a large number of common effluent treatment plants are not functioning properly.

Whether command and control or participatory approaches are taken, SPCBs must be well-equipped, yet they are currently required to operate with inadequate staff and funding.

3.3. Sectoral policies related to groundwater use and pollution

Because of the cross-cutting nature of water, many other policies and programs outside the purview of the water policy have an important bearing on the sustainable development and management of groundwater, including the following: (a) land use; (b) agricultural development (including use of agrochemicals) and pricing; (c) industrial and mining development, location and licensing; (d) sand and gravel mining; (e) solid waste disposal; (f) road development; and (g) tourism.

In most environments, the modalities of groundwater use are strongly contextual. In agriculture, for example, groundwater use depends significantly on energy options and costs of pumping, availability of surface irrigation, and cropping choices. Similarly, the unreliability of urban domestic and industrial water supplies is the primary driver of self-provision through private wells in urban areas. Table 7 presents an overview of these sectoral linkages. Of all these sectoral linkages, the one between groundwater use and policies pertaining to provision of power to farmers is so prominent in India that it is referred to simply as the “energy-groundwater nexus.”

Table 6: Main Indian policy and legal ordinances related to pollution issues in hot-spot states

POLLUTION ISSUES ACCORDING TO SOURCE	NEP 2006	NWP 2002	BWR 1998	CJ	CRZN 2010	EPA 1986	HWR 1989	IA 1968	NGTA 2010	PMB 2008	PARA	SGWACs	SWMR 2000	WPCPA 1974	WPCPCA 1977
INLAND SALINITY															
Inherent Salinity						X									
Water Logging Under Surface Irrigated Areas						X									
COASTAL SALINITY															
Saline Ingress						X									
Sea Water Intrusion						X									
GEOGENIC															
Arsenic						X									
Fluoride						X									
Iron														X	
ANTHROPOGENIC															
Mining						X								X	
Industrial						X								X	
Tanneries						X								X	
Distilleries						X								X	
Landfill & Garbage Dumps			X				X						X		
Agriculture						X				X				X	
Lack of or Poor Sanitation						X								X	

X most relevant agency for each issue

Source: Sengupta 2010.

Table 7: Main groundwater-related policies and scope for coordination and synergy

Policy area	Description	Current situation and action needed
Crop policy		
Food crops procurement	Major impact on cropping patterns due to purchases and price guarantees	Minimum support prices for some water-intensive crops like paddy are a key constraint for crop diversification in many states
Subsidies on inputs		
Electricity	Subsidized power at odds with groundwater sustainable management but major burden on state exchequers is the key problem	Free electricity for irrigation pumping in place in several states; high-level dialogue toward effective application of realistic tested measures urgently needed
Micro irrigation	Better if linked to local supply, service network, & demand management measures	Programs popular when linked to improvements in crop productions and ease of use
Moisture management	Mulching, composting, and improved field irrigation can reduce water consumption	Some projects and pilots support extension services covering soil moisture management
Recharge Programs		
Rainwater harvesting and recharge	Potential to increase recharge, but challenge is maintenance, farmers' investment, and link to demand management	States and central government implementing large-scale programs, but unlinked to water demand measures
Sand and gravel mining	Sand and gravel loads of rivers key in storing flood water and in recharge; sand dams can also harvest sand	Abstraction in India is largely uncontrolled, and many local river sections are being depleted
Land use planning		
Protection of recharge areas	Designated sensitive areas can help control polluting activities	Not yet common in India, even close to urban areas
Road planning	Roads can retain, channel, and recharge water, but inadequate cross-drainage can cause water logging	Ambitious yet only partly fulfilled plans to improve the national road network in India; linkage opportunities should be explored
Housing	Building codes can include roof water collection and recharge of aquifers	In place in several major cities; care is required to ensure harvested rooftop water can infiltrate
Solid waste disposal	Hazardous waste landfills need careful siting and seal to prevent contamination of groundwater	Proper management strategies and regulation implementation urgently needed to cope with massive

Policy area	Description	Current situation and action needed
		widespread problem in India
Petrol pumps	Oil and petrol leaks can be major contaminant of groundwater	Hardly any effective regulation
Economic Planning		
Tourism	Can place a high groundwater demand, especially in fragile coastal areas	With over 382 million per year, domestic tourism in India is on the increase; planning of water supply and waste disposal required
Sugar mills	Should be located in areas with ample water supply away from hard-rock aquifers	Several located in fragile groundwater dependent areas; needs to be avoided
Industrial estates	Encouraging small and medium industries to relocate to industrial estates with local wastewater treatment facilities to avoid dispersed pollution	In several states there is a move to central wastewater processing units on industrial estates; could be useful, but requires careful assessment for not concentrating pollution
Industrial planning	High water consuming plants should be sited in areas with adequate water supplies	The Coca Cola case in Kerala highlighted the need to make use of the provisions in the relevant state acts (Pollution Control Act, EPA Act, and Groundwater Act) and couple this with regulatory provision by the local government.
Mining	Several areas in India seem to have promising deposits but careful protection is required from pollution from mine tailings, and there is considerable scope for “waste to resource” programs.	Groundwater protection around mining areas in India is still in its infancy and more work is required, especially around selected hot spots

Source: WB 2010: Sec3:51.

Note: Actions: A = Scope for improvement and upscaling; B = Major need for improvement and change

Most of the states are providing electricity to farmers at a heavily subsidized flat tariff, whereby farmers are charged a fixed rate (based on the pump horsepower) independent of the actual amount of electricity consumed. Some states are also providing free electricity to farmers. In addition to the perverse incentives it creates for groundwater pumping, free or cheap power is also a severe threat to the bottom line finances of state electricity boards, which are saddled with losses incurred from massive nonrevenue exposure to the agricultural sector.

In the current environment, where in practice no direct legal or administrative control exists on groundwater use and there are very limited controls on groundwater pollution, the economic signals in agriculture, power, and other sectoral policies have become the prime determinants of groundwater use, even though these policies were designed without any consideration of their possible impacts on groundwater use and they are difficult to reform.

3.4. Institutions and capacity for groundwater management and protection

3.4.1. Groundwater management

Through the National Environmental Policy and National Water Policy, the central government is expected to play a role in the direction of groundwater development and management in the country. The Central Groundwater Authority (CGWA) is charged with the regulation and development of groundwater as a prime natural resource of national importance. The CGWA includes the representative of and is headed by the chair of the Central Groundwater Board (CGWB), which is a dedicated groundwater research/resource assessment and monitoring agency on the national level (under the Ministry of Water Resources). The CGWB provides support to the State Groundwater Boards (SGBs), who are responsible for these activities on the state level.

In addition to the CGWA and CGWB, the various agencies at different levels in the government that are important actors in groundwater development and use are shown in Table 8. This large number of agency players impacting a vital resource without effective coordination or regulatory oversight translates into a significant governance challenge for groundwater management in India. Other challenges are:

- The roles and responsibilities between state and central groundwater institutions are not sufficiently defined.
- The CGWA's rules for regulation, development, and management of the resource are still pending approval and many states have reservations regarding its mandate given that groundwater is primarily a state subject.
- Although the CGWA and CGB have the potential to become champions of sustainable groundwater management in India, the continued lack of clarity over their status and chronic understaffing means central government institutions cannot properly fulfill their functions and effectively support state agencies.

The institutional and administrative environment also varies considerably between states, and the shortcomings in the state agencies represent a major constraint for groundwater governance in India.

Table 8: Main government agencies relevant to groundwater management

Level	Unit	Main functions	Ground water resources	Water services
Central Groundwater Development & Management	Central Ground Water Authority	Established in 1997, following Supreme Court orders, mainly to regulate, control, manage, and develop groundwater resources in the whole country and support states	O	
	Central Ground Water Board	Established in 1950 for dedicated groundwater research and monitoring, to support overall planning for development of groundwater resources in the country, and to provide support to states	O	
	Central Pollution Control Board	Norm setting on industries' water use and wastewater discharge	O	O
	Ministry of Commerce and Industries	Policy decisions and water use norm setting on water related to industry	O	O
	Ministry of Environment and Forests	Planning, promotion, coordination, and overseeing implementation of environmental and forestry programs and implementing the Environment (Protection) Act 1986	O	
	Ministry of Rural Development	Rural development, land resources, and drinking water supply	O	O
	Ministry of Urban Development	Implementing the nationwide Jawaharlal Nehru National Urban Renewal Mission, with significant interventions in water supply, sewerage and sanitation; Water supply and sewerage for the National Capital Territory of Delhi and the Union Territories	O	O
	National Water Board	Established in 1990 under Ministry of Water Resources, apex organization with responsibility for progress achieved in implementation of National Water Policy and other issues, reports to National Water Resources Council	O	O
	National Water Resources Council	Established in 1983 with prime minister as chair, minister of water resources as vice-chair, and concerned Union ministers/ministers of State, chief ministers of all states, and lieutenant governors of union territories with secretary of Ministry of Water Resources as member secretary	O	O
	Ministry of Water Resources	Setting policy guidelines and programs for development and regulation of the country's water resources, but functions specific to groundwater resources through Central Ground Water Board	O	
	Oil and Natural Gas Commission	Member of Central Ground Water Authority and supplements deep well logging information	O	

Source: WB2010, section 3.49.

3.4.2. Groundwater quality protection and pollution control

The Central Pollution Control Board (CPCB) provides technical assistance on all subjects related to water pollution, coordinates state bodies, and maintains a network of groundwater monitoring stations to assess water quality throughout the nation. The State Pollution Control Boards (SPCBs) are responsible for the prevention and control of water pollution as well as the prosecution of offenders.

In 2001, the Ministry of Environment and Forest (MEF) established the Water Quality Assessment Authority (WQAA) to coordinate the numerous water management agencies throughout the country. In addition to data collection and analysis, WQAA has strengthened the water quality monitoring capacities of states by establishing standardized monitoring protocols and facilitating the creation of state-level Water Quality Review Committees, which review and interpret state water quality data. Other important water-related institutions include private sector companies that supply technology and training, academic research institutions, and local organizations responsible for decentralized monitoring activities as well as the operation and maintenance of water supply systems.

The Bureau of Indian Standards (BIS) determines national water quality standards for various purposes, including agriculture and drinking. The drinking water standards are established on the basis of health risks in conjunction with technical and economic factors required for implementation and enforcement.

3.5. Capacity and knowledge

The institutional technical capacity both at national and state levels is generally weak – this in spite of having a very high level of professionals. There are simply not enough staff to undertake the tasks required for groundwater management and protection. The shortage of staff is now a universal problem in India and no breakthrough may be anticipated either in CGWB or CPCB. On the other hand, a preliminary survey of groundwater-related universities and research institutions (Annex 3)—and the wide range of Indian books and scientific publications in a large number of groundwater-related journals—show no lack of knowledge base and high-level research capacity.

This situation is not exclusive to India; the weak linkages between managers and researchers are common to most developing nations. Thus, there is urgent need to (a) explore and expand collaboration between the research and academic institutes (both on the national and international levels); and (b) improve collaboration through a data sharing policy. If data were made accessible (mostly at no direct cost), more research institutes would be interested in conducting applied research.

A national conference on required linkages between government groundwater managers and the academic community could help in systematically identifying areas of opportunity to increase this much-needed synergy. This could also help in tailoring undergraduate and graduate courses to practical resource management and link it to pressing real-life groundwater problems.

3.6. Groundwater quality monitoring and surveillance

With the steadily increasing pollution of groundwater in India, monitoring and surveillance of groundwater quality has achieved much importance. The NWP adopted by the government in 2002 stresses regular monitoring of both surface and groundwater quality. Table 9 shows the agencies involved in these activities.

The Hydrology Project 1 (HP-I), with World Bank IDA credit assistance, was implemented in nine states between April 1996 and March 2003. It was aimed at “improving the institutional and organizational arrangement, technical capabilities and physical facilities available for measurement, validation, collection, analysis, transfer and dissemination of hydrological, hydrometeorological, and water quality data for basic water resource evaluation within the concerned agencies at Central Government level and participating states.” Six central agencies (CWC, CGWA, CGB, CWPRS, NIH. and IMD) participated, along with the state agencies of Andhra Pradesh, Chattisgarh, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, and TamilNadu.

CGWB expanded its groundwater monitoring network during HP-I and constructed 2,239 purpose-built piezometers. The Chemical Quality Laboratories were upgraded at 14 stations and 28 offices of CGWB set up a computer data center. Dedicated groundwater estimation and management software (GEMS) was developed for ensuring uniformity in data processing, storage, and dissemination.

Table 9: Main agencies relevant to groundwater quality monitoring

Level	Unit	Main Functions
CENTRAL	CGWB	Monitoring groundwater quality for last 40 years through its Hydrographs Network Stations, primarily for assessment of groundwater resources. Presently, 15,640 monitoring stations in the country collect groundwater samples once a year in April/May to provide regional picture, water samples collected from exploratory boreholes drilled throughout the country for area specific problems of groundwater pollution.
	CPCB	Water quality monitoring programs closely related to their special mandates such as control of Industrial pollution or safe drinking water supply.
	NEERI	Limited agenda of area-specific groundwater quality monitoring and surveillance.
STATE	Various Educational & Research Institutions	Limited agenda of area-specific groundwater quality monitoring and surveillance.
	Groundwater Organizations	With wider network of Hydrograph Network Stations—yet, barring a few, regular monitoring of groundwater quality not effectively done in most states. Limited monitoring for special problem areas of geogenic and anthropogenic pollution.
	SPCBs	Water quality monitoring programs closely related to their special mandates such as control of industrial pollution or safe drinking water supply.
	SHEDs	

Source: Romani 2010

Issues addressed under HP-I included development of a water quality monitoring mechanism (including base line stations and trend stations) that is uniform among all participating agencies for comparative results. The water quality data was aimed to be transferred into information at data centers for fast dissemination among the user agencies.

There is no denying that under HP-I groundwater quality monitoring has shown a major improvement and useful data has been generated both at the central and state government levels. The chemical labs have been upgraded and useful training has been imparted to both central and state officers. However, much improvement is still needed for groundwater quality monitoring and desired continuity after the completion of HP-I and during HP-II (2006–12). Some of these are:

- There is a need to strengthen the network of groundwater monitoring and surveillance stations with specific purposes to check overexploitation and pollution from various activities.
- There is a need to strengthen SGWDs and emphasis on groundwater pollution issues before closing of HP-II in June 2012.

- The CGWQAA has issued a "Uniform Protocol on Water Quality Order 2005," which requires that all groundwater quality analysis for 25 parameters should be done two times a year (pre- and post-monsoon) in all baseline stations. However, the effective execution of this notification is still a distant dream.
- There is a basic need for identification of all the central and state agencies with well-defined responsibilities for groundwater quality monitoring.
- There is an urgent need to establish an effective groundwater quality monitoring network in coastal regions to monitor the impacts of cyclones and tsunamis on shallow aquifers.

3.7. Financing

Given the millions of water wells in India—mainly drilled, operated, and maintained by private users—and the scant institutional enforcement capacity, it cannot currently be expected that users can contribute toward groundwater management costs. There is, however, an outstanding issue that merits discussion: the "groundwater-energy nexus," and one possible way forward through up-scaling where feasible Gujarat's promising Jyotigram Scheme (Foster et al. 2008).

In recent years, the excessive consumption of electricity by Indian agriculture (currently a colossal 87,000 GWhr) has been hotly debated and remains a critical topic for the nation's future (Briscoe and Malik 2006). Most electricity consumed by agriculture goes to "pumping groundwater," or at least trying to pump groundwater. Energy-supply policy (especially the level and effectiveness of rural electrification) and pricing (especially the adoption of flat-rate tariffs according to pump capacity) have exerted a great influence on groundwater use for irrigated agriculture, but there are major differences among various Indian regions (Shah et al. 2004). For example, some areas (much of Gujarat, Maharashtra, and Andhra Pradesh) have high coverage of rural electrification and the supply (although intermittent) is "sufficiently predictable overall" for farmers to rely exclusively on pumpsets driven by electric engines, which receive a major subsidy via "flat-rate tariffs" and pay only 20 percent of the cost of the energy consumed. In other areas (such as much of Rajasthan and Uttar Pradesh) where rural electrification is more limited and/or where service levels are poor, farmers depend much more on diesel-engined pump sets, paying higher use-related rates for energy consumption.

The widespread depletion of groundwater tables over the last 10–15 years due to intensive abstraction for irrigated agriculture has become a major concern. In many areas, this has occurred more-or-less year-on-year, except for a partial (but temporary) recovery following years of exceptional monsoon rainfall. Depletion of the resource base has already had other impacts, such as yield failure or quality deterioration in public-supply water wells.

Flat-rate electricity tariffs are not the primary cause of excessive groundwater exploitation and declining water tables, because this condition also occurs in areas where farmers use diesel-engined pumpsets. Moreover, energy consumption (even without subsidy) represents only a minor proportion of total crop production costs. The underlying reason is the growth of dry-season abstraction for crop irrigation to levels well beyond the average rate of aquifer replenishment from monsoon rainfall.

Viewed from a groundwater perspective, the overriding policy need is to find a mechanism to facilitate recovery of aquifer water levels such that the most productive horizon of weathered hard-rock aquifers remains partly saturated in the dry season. The benefits of this would be a major reduction of electricity consumption for only a modest reduction in irrigation water-supply availability and crop production

4. CASE STUDY AQUIFERS/PILOT PROJECTS

4.1. Introduction

Given that hard-rock and major alluvial aquifers underlie most of India's land, seven representative cases in the rural and urban environments with different socioeconomic features were selected as pilot projects:

- Aquifers subject to intensive abstraction in hard-rock rural areas:
  - Weather zone of the Deccan Traps Basalt underlying Maharashtra and Andhra Pradesh (4.2.and 4.3)
  - Low-storage variably weathered crystalline basement aquifer underlying most of drought prone Tamil Nadu (4.4)
  - Elevated alluvial areas of the Indo-Gangetic Peneplain of central Punjab state with relatively deep water tables (4.5)
- Aquifer subject to intensive abstraction in hard-rock urban area:
  - Deccan Traps basalt lava flows, with groundwater confined to the weathered horizon, underlying Aurangabad in the drought-prone interior of Maharashtra (4.6)
- Aquifers subject to intensive exploitation in the alluvial tracts of the Ganges Valley:
  - Aquifer system of layered sand-silt deposits in the rural area of Uttar Pradesh state (4.7)
  - Large thickness of quaternary alluvial sands with "three productive horizons" underlying Lucknow City in Uttar Pradesh (4.8).

A typology of intensively exploited aquifers is proposed in Table 10 along with the selected case study aquifers and key local groundwater governance issues, as well as the GW-MATE references where they can be studied in more detail.

Table 10: Typology of intensively exploited aquifers in India

General and specific hydrogeological environment		Resource use	Pilot Projects[1]
Hard-Rock Terrains of Rural Peninsular India	Widespread weathered hard-rock (basalt or granite**)** aquifers with shallow, low-storage patchy groundwater bodies	Subsistence and commercial agr. use , drinking water supply, some industries	**Maharashtra** (CP-22 & SO-4) **Andhra Pradesh** (CP-19 & SO-4) **Tamil Nadu** (CP-11)
	Occasional but important groundwater bodies in coastal or graben-fill sedimentary aquifers		
Major Alluvial Formations of Rural Indo-Gangetic Plain	Alluvial aquifers, in plains largely within major irrigation canals commands with naturally shallow water table	Mainly subsistence and commercial agricultural exploitations	**Uttar Pradesh** (SO-2 & SO-4)
	Alluvial aquifers in the "peneplain" area between the alluvial plains, with more limited irrigation canals and deeper water table		**Punjab** (SO-2 & SO-4))
Urban Environment	Weathered hard-rock aquifers with shallow, low-storage patchy groundwater bodies	Individual urban households, water utilities, industries, tourism	**Maharashtra** (CP-21)
	Major alluvial aquifers in alluvial plains		**Uttar Pradesh** (CP-23, SO-2 & SO-4)

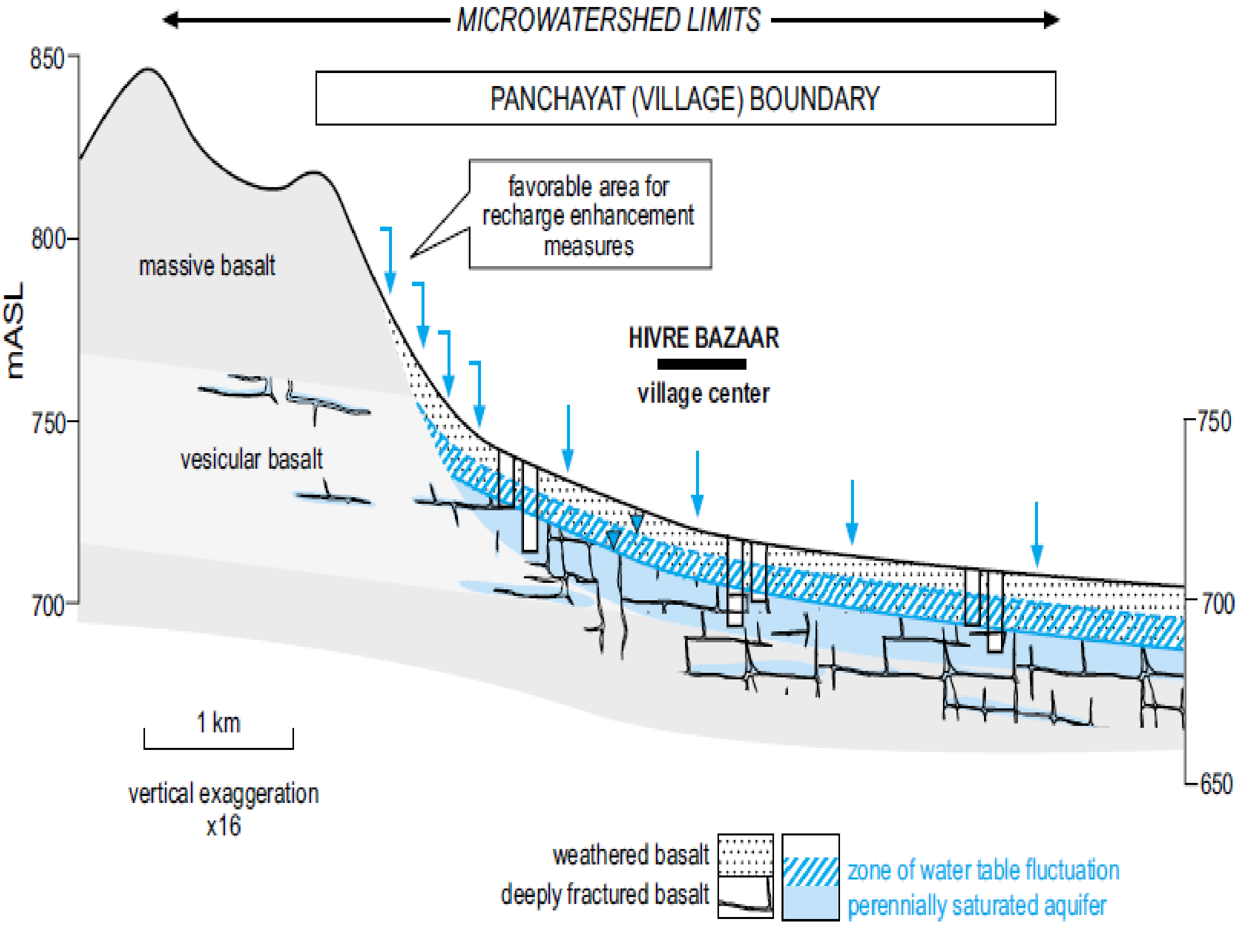
Source: WB 2010, xii.
Note[1] Codes refer to GWMate publications CP = Case Profile; SO = Strategic Overview

4.2. Weather zone of the Deccan Traps Basalt in Maharashtra

4.2.1. Description

Hivre Bazar is a village of 1,200 population and 975ha area in the elevated drought-prone Deccan Traps country of Maharashtra (450 mm/a average rainfall) (Figure 6). Here the weathered zone reaches to about 12–15 m bgl and is underlain by massive basalt, providing only very limited additional groundwater flow.

Figure 6: Simplified hydro geological section of Hivre Bazaar micro-watershed methodology of study



Source: GW-MATE 2009a.

4.2.2 Management issues

In Hivre Bazar, staple crops are grown primarily for home consumption with residues serving as livestock fodder or domestic fuel, while most pulses, onions, vegetables, and flowers are sold at market. In the most favorable years, almost 60 percent of the land can be irrigated, but in drought periods wheat and summer crops have to be radically reduced. The main groundwater-related decisions of the Village Council (on its Chief's advice) during the mid-1990s were (a) prohibiting the use of bore wells for agricultural irrigation, which had the great benefit of moving farmers' minds and resources away from "competition for deeper groundwater" to cooperation on maximizing benefits from groundwater; (b) subjecting the micro-watershed to comprehensive reforestation and water harvesting, notably hill contour trenching, Nalla stream bunds, and a livestock grazing ban; and (c) banning sugar-cane cultivation, given its high water use and other implications.

4.2.3 Management response

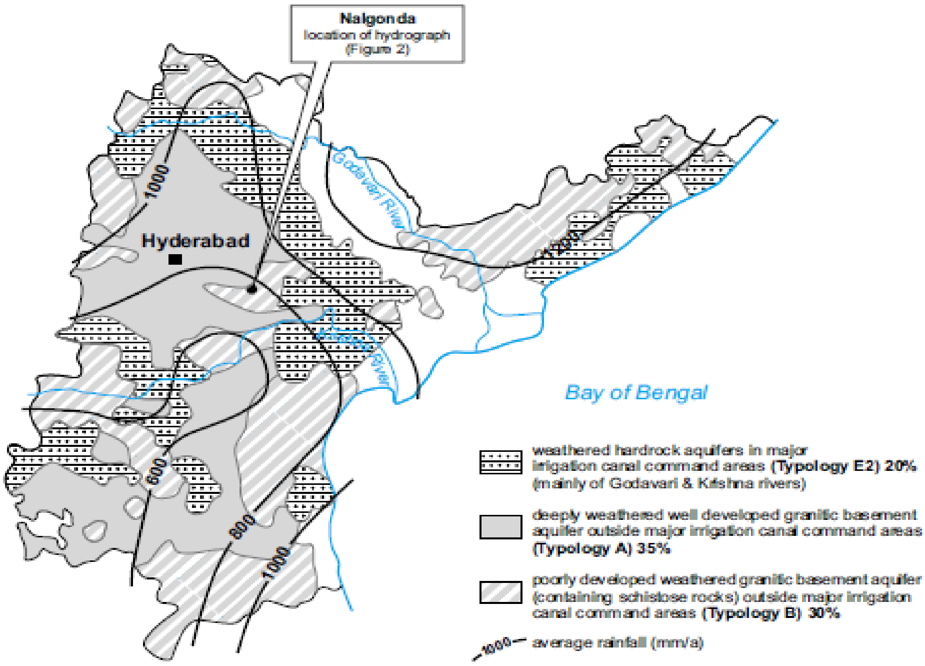
Under the leadership of an informed and charismatic Village Council chief, a concerted effort on groundwater management commenced in 1994 (as part of the Maharashtra Ideal Village Social Development Scheme) with implementation of a comprehensive 5-year plan following a long history of drought propensity and land degradation, with farmers struggling to maintain a kharif crop and feed their families and cattle without leaving the village periodically to search for paid work. Most importantly, village-level crop-water budgeting was introduced in 2002 and in dry years villagers are asked to reduce their proposed irrigated area and to give preference to low-water demand crops, with mutual surveillance usually being enough to achieve compliance. Such proactive groundwater management has resulted in a marked contrast between Hivre Bazar and most surrounding villages. As many as 32 dugwells produce important revenue in the dry season from irrigated onion, vegetable, and flower cultivation, and only a few in the upper watershed dry out. The household-level benefits of community land and water management resulted in household incomes rising markedly (to over $500 per year on average) and land values appreciating many-fold in the past 15 years.

4.3. Weather zone of the Deccan Traps Basalt in Andhra Pradesh state

4.3.1 Description

Andhra Pradesh is mainly underlain by granitic basement rocks (Figure 7), that have been fractured and decomposed by repeated cycles of tropical weathering to create a shallow "low-storage" aquifer system annually recharged to varying degrees by monsoon rains. In its most favorable typology, the groundwater body has 15–25m thickness along lineaments below topographic lows thinning on higher ground, but elsewhere more schistose bedrock leads to groundwater bodies that are more patchy and thin. Most "natural groundwater flow" is concentrated in a 5m or so horizon at the interface between the weathered and fractured zone. Average rainfall totals 650–950 mm/year, but is highly concentrated in a single monsoon season (June–August), during which "natural recharge rates" are believed to average 70–100 mm/year.

Figure 7: Simplified hydro geological sketch map of Andhra Pradesh



Source: GWMATE 2009b

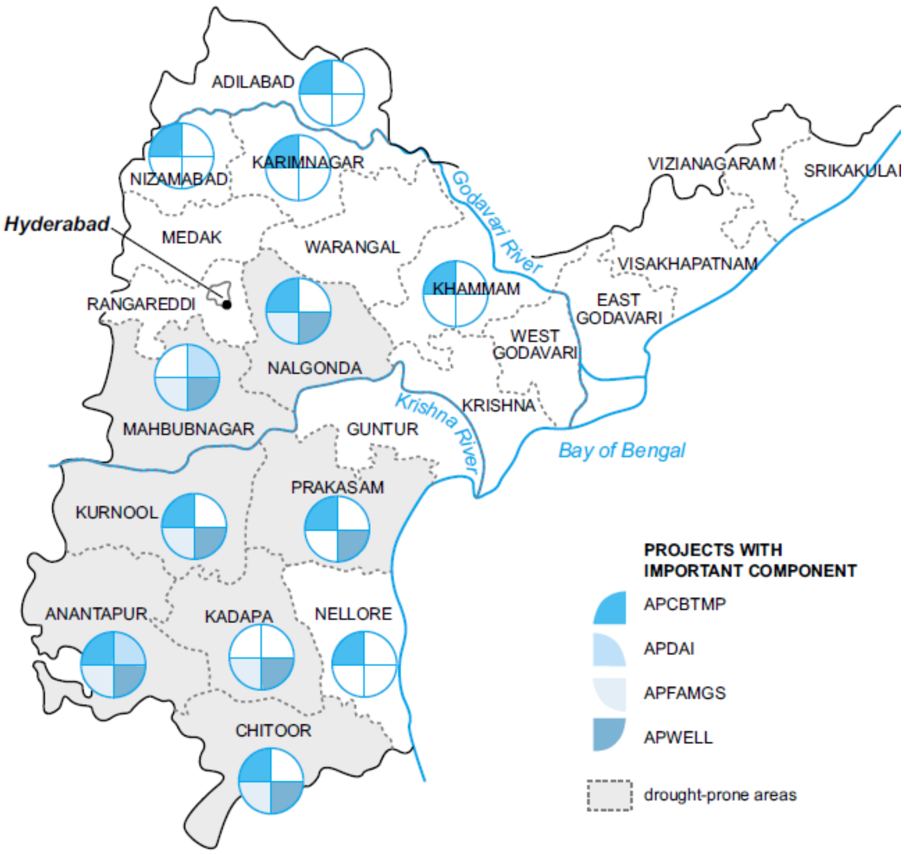
4.3.2 Management issues

By the late 1990s, groundwater abstraction rates had grown to an equivalent of 120–150 mm/year. During the past 30 years, the number of dugwells has remained at about 900,000, but with an increasingly large portion falling dry or becoming seasonal, there has been rapid growth in the number of borewells, which are currently estimated at 1.7 million (with average depths steadily increasing). But this massive expansion of groundwater use has had serious impacts, including (a) widespread intensive exploitation of available resources with serious dewatering of the main water-bearing horizons of the shallow aquifer system; (b) inefficient borewell pumping practices (related to the flat-rate rural electricity tariff), with farmers continuing to operate pumps at far too deep groundwater levels, causing large well entry/pump friction losses, and leaving pumps switched on to obtain a supply when the (discontinuous) power activates.

4.3.3 Management responses

The pioneering APWELL Programme (Figure 8) of the 1990s covered some 14,500 marginal farmers using 14,000ha of irrigated land in 370 villages in most of drought-prone Andhra Pradesh. It developed participatory hydrological monitoring to provide farmers with the necessary knowledge, data, and skills to understand groundwater resources and to manage their use through controlling on-farm demand for water, without offering any cash incentives or subsidies.

Figure 8: Location of the principal experience with CBGWM in Andhra Pradesh



Source: GWMATE 2009b.

The subsequent APFAMGS Programme (Figure 8), which commenced in 2007, makes the strong link between groundwater availability and irrigation use but leaves farmers free to make crop planting decisions and extract groundwater as they desire. Nevertheless, in a majority of pilot project areas the results have been very positive, as witnessed by (a) a reduction in groundwater use through crop diversification and irrigation water-saving techniques, with 42 percent of areas consistently reducing the rabi groundwater overdraft over 3 years and a further 51 percent achieving intermittent reductions; and (b) farmers improving profitability despite less water use, with the reduction in groundwater overdraft coming from multiple individual risk-management decisions rather than “altruistic collective action.”

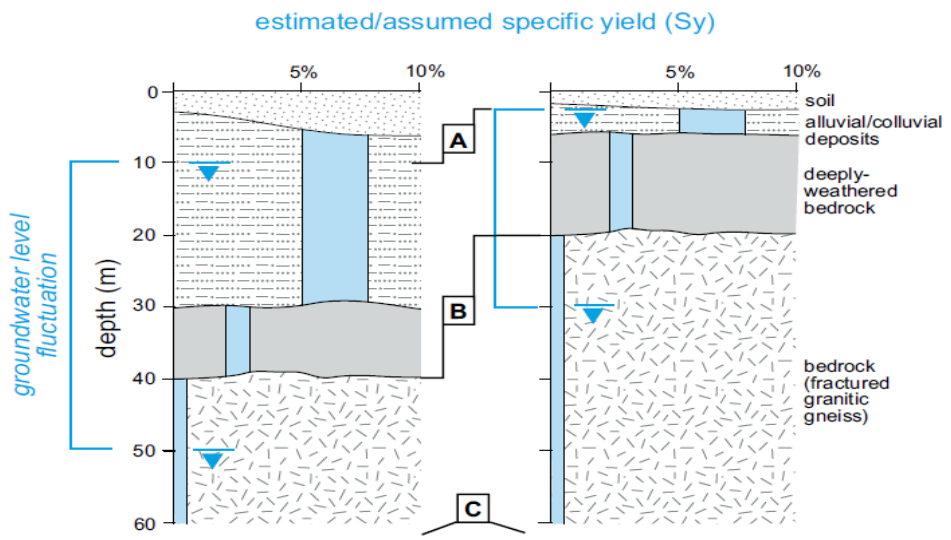
The up-scaling and replication of this very positive experience will necessitate a flexible phased approach that engages experienced support organizations, together with development of a “lighthouse function” in the state.

4.4. Low-storage variably weathered crystalline basement aquifer in Tamil Nadu state

4.4.1 Description

Tamil Nadu covers an area of 130,058 km^2, of which 73 percent is occupied by variably weathered crystalline basement rocks, forming an extensive but minor, low-storage aquifer (Figure 9). Groundwater is mainly confined to the weathered mantle, with more localized flow in fractures, joints, and lineaments of the underlying bedrock. The major rivers tend to have eroded through the weathered zone, mainly flowing on beds of exposed bedrock, and today have no significant base flow.

Figure 9: Typical weathered basement aquifer profiles with estimates of available groundwater storage



PROFILE		FAVORABLE AREA	TYPICAL AREA*
drainable ground-water storage (mm)	A-B	**1200 - 1950**	**275 - 475**
	B-C	**0 - 100**	**0 - 200**

* unfavorable areas have no alluvial/colluvial deposits and thinner weathering zone with total storage equivalent to less than 250mm

Source: GW-MATE 2004.

Primary groundwater recharge occurs directly as a result of monsoon rainfall in excess of plant moisture requirements and soil moisture deficits, but is limited by soil infiltration capacity with higher intensity rainfall forming surface runoff rather than groundwater recharge. Indirect primary recharge (from streambed and irrigation tank infiltration) is not significant and secondary recharge (infiltration from irrigation agriculture and urban water mains leakage/sanitation percolation) does not represent “new water” unless the original water supply was derived from a surface water source.

4.4.2 Management issues

The growth of the rural population and a major increase in dry-season irrigated agriculture has led to overexploitation of groundwater resources across wide areas. The current trend of “chasing” the declining water table in search of deeper water-bearing zones entails a high risk of drilling dry or very low-yielding wells in the crystalline basement (except close to major fault zones associated with up-lifted hill blocks). An alternative for village water supply might be the acquisition of local higher-yielding irrigation wells, but the demands of dry-season crops under severe water stress and the pressure on irrigators to secure dry-season production to pay off bank loans secured to invest in deep water well construction tends to work against this option. On reflection, it is difficult to identify “winners” among the enormous hardware investment chasing a limited groundwater resource, except perhaps water-well drilling companies and equipment manufacturers.

4.4.3 Management responses

Aimed at improving domestic rural water supply sources, a number of recharge enhancement actions have been undertaken by the state government. They have been shown to be effective, especially where they comprise part of systematic watershed management and act as a focal point for local community action on water conservation.

It is important to stress that recharge enhancement structures will only be effective for easing the problems of drinking-water sources if (a) a suitable site for groundwater recharge is located close to the drinking-water source(s) requiring rejuvenation or convenient to the habitation; and (b) community administration (Panchayat leaders and District controllers) can ensure that new irrigation wells are not permitted in the vicinity (say within 500 m) of the recharge structure using through their power to refuse new connections to the rural electricity grid.

A further concern in this context is the frequently large number of dormant irrigation wells, which are unused because of falling groundwater levels but still with electricity connections. There is clear evidence from the Dindigul District research area that the introduction of recharge enhancement structures led to reinstatement of irrigation wells, thus stimulating dry-season demand, and that falling groundwater levels and difficulties for drinking water sources continued. Thus for a long-term trend in aquifer depletion to be reversed, a more integrated approach is required that addresses both optimization of recharge enhancement opportunities and complementary demand-side management actions—and pays attention to the pros and cons (Table 11) of such approaches.

4.5. Elevated alluvial areas of the Indo-Gangetic Peneplain of central Punjab Sate

4.5.1 Description

Over most (but not all) of Punjab, the alluvial outwash aquifer system (Figure 10) is relatively thick (>150m) and represents a major source of groundwater. The central part of Punjab provides an important example of a successful “state policy approach” to address intensive use of this groundwater—and relates to the elevated alluvial areas of the Indo-Gangetic Peneplain, where water tables are relatively deep and coverage of irrigation canals is not all that extensive.

Table 11: Qualitative assessment of groundwater recharge enhancement schemes

PROS	CONS
• Some increase in agricultural production through reactivation of disused irrigation wells and increased security for planting higher-value dry season crops • Some village groundwater sources improved in quality and/or dry-season yield • Stimulus for formation of village-level water resource associations / committees • Promotes dialogue between local government, social NGOs, village authorities, and community on water resource issues • Provision of work and mobilization of rural landless laborers in construction	• Distracting attention from more pressing need for irrigation demand management and increasing productivity of scarce groundwater gives impression that a simple single solution to groundwater resource problems exists • River basin approach and upstream-downstream impacts (on streamflow and irrigation tank filling) often ignored and never costed into scheme pre-appraisal • Successful short-term local recharge enhancement often just leads to more active irrigation wells, with groundwater resource imbalance, competition, and sustainability problems continuing • Not necessarily (or usually) focused on rural poverty alleviation (apart from creation of short-term employment in construction) • May lead to corruption practices and ineffective use of water

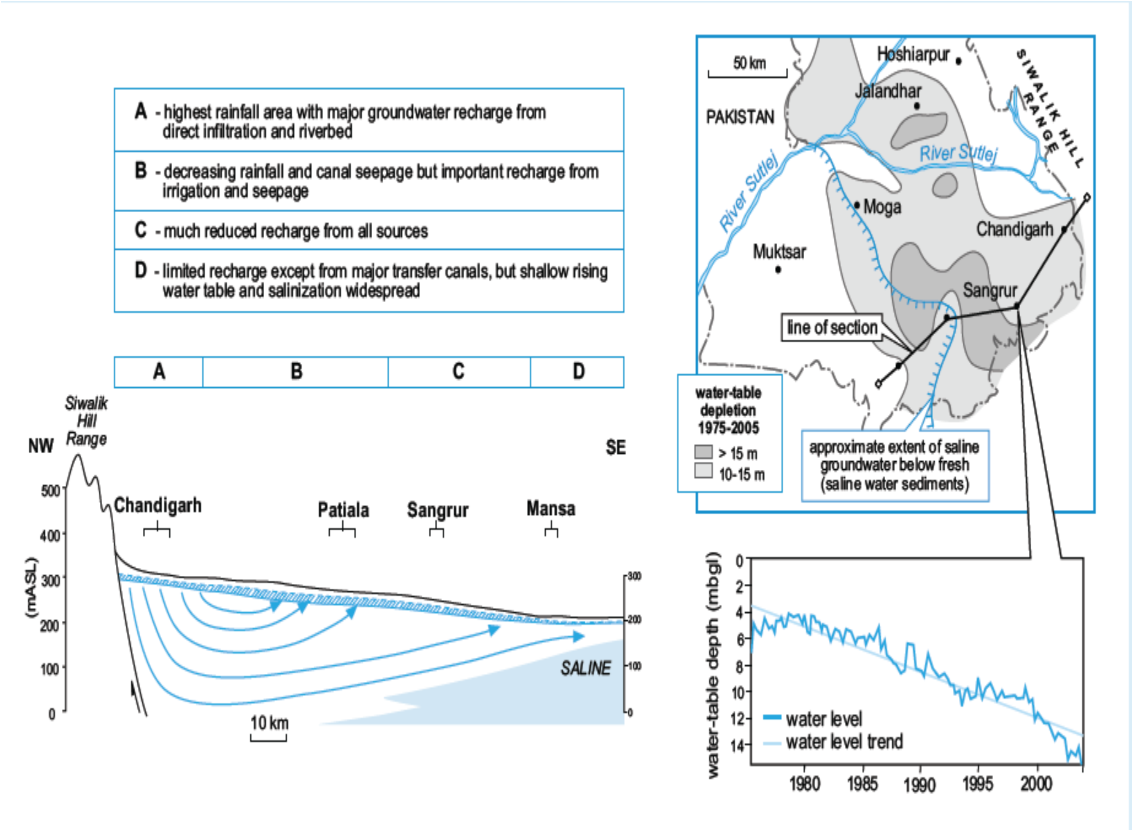
Source: Foster and Garduño 2009

4.5.2 Management issues

A major part of Punjab's agricultural success has been based upon the use of groundwater for irrigation. The number of operating tubewells has increased from 500,000 in the 1970s to 2.3 million in 2008. Some 70 percent of the area now under irrigated cultivation is dependent on groundwater, since the surface-water canals can only meet a minor proportion of current agricultural demand. The consequences of this massive and uncontrolled development of groundwater is that the water table has been in continuous decline, with depletion rates currently in the range 0.6–1.0 m/year (equivalent to a net overall rate of intensive abstraction in the range 120–180 mm/year), except in the down-gradient saline groundwater zones.

While storage depletion is in itself not critical (being partly an inevitable significant consequence of groundwater development), it is resulting in mounting cumulative costs for (a) the state government, which underwrites most of the cost of rural electrical energy; and (b) farmers, who are being confronted with the need to move from low-cost water wells to deeper tubewells with electric submersible pumps, resulting in adverse impacts on those farming the least land.

Figure 10: Map and cross-section of Punjab peneplain with different recharge areas and water level trend



Source: GW-MATE 2011

4.5.3 Management responses

While an array of interventions are likely to be needed in the longer run to reduce groundwater use to sustainable limits, certain technical demand-management interventions related to paddy-rice cultivation (far-and-away the largest consumer of groundwater resources) were identified that could be implemented immediately to good effect. In 2008, a state government ordinance was issued prohibiting transplanting of paddy rice until June 10—the onset of monsoonal rain and 35–40 days later than normal. Agronomists identified that evaporation rates from paddy during this period were very high and there was potential for making real water savings by eliminating essentially nonbeneficial evaporation totaling more than 90mm. While this change did not necessarily impact on crop yields, it presented some complications for farmers in terms of labor availability for planting seedlings.

The expected water resource saving was equivalent to 50–65 percent of the groundwater overdraft and that of electrical energy statewide amounted to 175 million kWh. The measure was highly successful because (a) there was limited farmer resistance because yields were not negatively impacted; (b) compliance was more than 95 percent because any violations were highly visible and severely sanctioned (fine of $200/ha plus uprooting of crop); and (c) once a critical mass agreed to delay transplanting, farmers who did not comply also faced an increased threat of pest infestation.

Given the success, this measure was incorporated into the Punjab Preservation of Sub-Soil Water Act of 2009. Additional measures also were considered such as laser-leveling of fields, soil-moisture-based irrigation timing for winter wheat, and shorter-duration rice varieties (with 15 days less gestation). These measures were all aimed at increasing crop-water productivity and reducing nonbeneficial evaporation so as to eliminate the current groundwater irrigation overdraft.

Now, after a few years of operation, it is essential to closely monitor the aquifer water-level response and to check that other components of the groundwater balance are not experiencing any parallel changes. While over 70 percent of the irrigation water supply is derived from tubewells, as much as 35 percent of total groundwater recharge arises from seepage from the extensive (but inefficient) irrigation canal system. If this seepage were reduced by engineering measures (such as canal lining) with the intention of diverting water to demands in other areas, the effect on the local groundwater resources would be very detrimental.

4.6. Deccan Traps basalt lava flows underlying Aurangabad, Maharashtra

4.6.1 Description

Aurangabad City, in the drought-prone interior of Maharashtra State, has only limited groundwater resources, both in terms of resource availability and well-yield potential (GW-MATE 2008). It is underlain by Deccan Traps basalt lava-flows, with groundwater confined to the weathered horizon and generally moving southwest along the Kham River valley. Post-monsoon groundwater levels are around 6m bgl, but fall to below 10m bgl during the dry season, and locally have reached 30m bgl (with the weathered zone completely dewatered) by heavy pumping. Groundwater development mainly uses bore wells equipped with small (0.5–1.0 bhp) pumps, together with over 600 (mainly handpump) Aurangabad Municipal Corporation (AMC) water wells to supplement its supply.

4.6.2 Management issues

Aurangabad City has grown rapidly over the last 20 years and now has an urban area of 138 km^2 and a population of 1.1 million. Prior to 1975, traditional sources (“nahars”) delivered some 5–15 Ml/d, but following the 1972 drought the authorities opted for a preferential supply from the Jayakwadi Reservoir (some 45 km distant and at 180 m lower elevation). The reservoir was rated at 28 Ml/d in 1975, 56 Ml/d in 1982, 100 Ml/d in 1992, and 150 Ml/d in 2005. Given electrical power shortages for high-lift pumping and limited storage in the urban distribution system, the service level of AMC water supply is very poor (widely less than 1-in-24 hours), resulting in most residential properties and many commercial/institutional water users drilling private borewells and/or purchasing water from tankers as a supplement.

4.6.3 Management responses

Since 2004, AMC have been considering a scheme to increase the imported water supply to 325 Ml/d, but requires a large investment ($80 million) and the scheme would also have high recurrent costs, raising serious doubts about cost recovery and financial viability. Anticipating the need to considerably increase its revenue, the AMC has been trying, against popular resistance, to introduce volumetric charging. Clearly, the widely established private access to groundwater will act as a serious constraint to future AMC cost recovery.

Planning future water supply in Aurangabad (and many similar cities of peninsular India) should not ignore the role of private self-supply from groundwater. It should be based on the following policy recommendations:

- Access to groundwater will unquestionably affect the "willingness to pay" for improved municipal supply of residential users and thus the viability of major new imported water-supply schemes.
- When planning future main sewerage improvements, the prevalent use and operational cost of groundwater from private waterwells should be taken carefully into consideration.
- In evaluating the benefits and risks of in-situ groundwater use, microbiological and chemical quality should be a factor taken into consideration and appropriate advice provided.
- The use of urban groundwater is in certain ways logical, especially for sanitary and laundry purposes, where a more expensive treated water supply may not be justified.
- Municipal authorities should provide further fiscal incentives and technical guidance to promote private action on roof and pavement water harvesting for aquifer recharge enhancement and for the reduction of groundwater pollution risk from wastewater disposal and hazardous substances.

When it comes to urban groundwater resource use, there remains an institutional vacuum in India that needs to be filled if realistic and robust policy implementation is to occur. In Aurangabad, a "standing committee on groundwater" drawn from the AMC and relevant state government departments and agencies could be formed to formulate policy on private groundwater use.

4.7. Aquifer system of layered sand-silt deposits in Uttar Pradesh state

4.7.1 Description

The vast alluvial tracts of the Ganges Valley are underlain by an extensive aquifer system of layered sand-silt deposits (up to 600 m thick), which represents one of the largest groundwater storage reserves in the world. These alluvial aquifers exhibit generally good water-well yield potential and are recharged directly from infiltrating monsoon rainfall (generally above 1,600 mm/a) and indirectly from surface-water via irrigation canal leakage and excess field application. Large-scale groundwater use for agricultural irrigation has developed spontaneously as a coping strategy by farmers experiencing inadequate or unreliable service from canal irrigation systems—and shows potential as an adaptation strategy for climate change scenarios predicting progressive reduction of Himalayan glaciers and of associated base flows in the main Ganges tributaries.

4.7.2 Management issues

As a result of intensive groundwater use for irrigation, over 50 percent of the Uttar Pradesh land area now has a falling water table. The consequences are increasingly evident in terms of irrigation tubewell dewatering, yield reduction, and pump failure, together with hand-pump failure in rural water-supply wells. Concomitantly, and sometimes in relatively close proximity (10–20 km distant) to the "groundwater overexploitation zones," canal leakage and flood irrigation in the "head-water zones" is resulting in around 20 percent of the land area being threatened by a rising and shallow water table, with soil waterlogging and salinization leading to crop losses and even land abandonment.

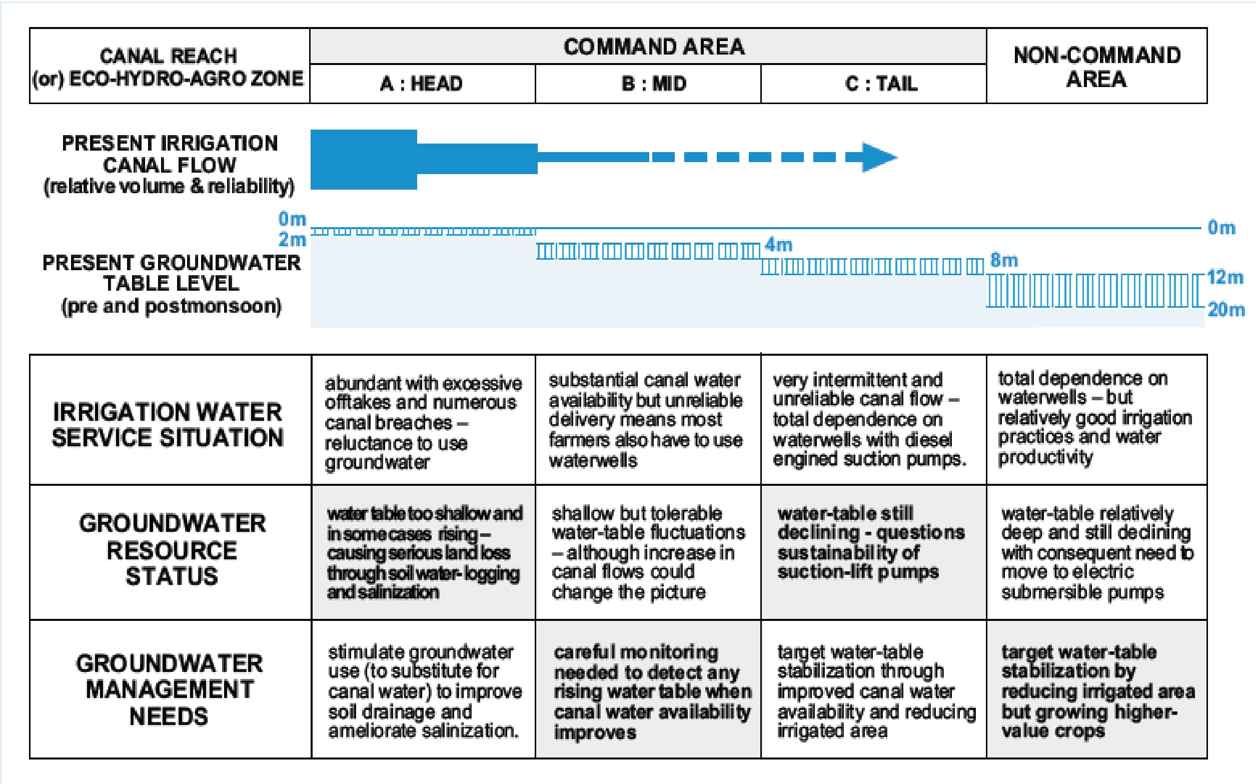
4.7.3 Management responses

This situation has been evaluated in considerable detail in the Jaunpur Branch canal-command area in central Uttar Pradesh. Integrated numerical modeling (soil, crops, canal, and aquifer) based on excellent field data shows that more "optimized conjunctive use" (with improved surface water distribution and use, complemented by more rational groundwater use) could increase the cropping intensity from about 140 percent to around 220 percent by reducing the growing sodic land problem and without compromising groundwater resource sustainability.

This has led to a more planned conjunctive-use approach through (a) completing and maintaining bank sealing and desedimentation of major irrigation canals; (b) enforcing existing operational codes for the distribution of canal water; (c) promoting the construction and use of tubewells (if necessary through subsidy and eventually through rural electrification) not only in non-command areas but also in high water-table areas; and (d) financial investment and extension in soil salinity mitigation and sodic land reclamation.

It is most important to pursue an appropriate management action plan in which the land surface has been subdivided on the basis of hydrogeologic and agroeconomic criteria into a number of small micro-planning and micro-management zones, with specific, required management measures to move to more efficient and sustainable conjunctive use (Figure 11).

Figure 11: Micro-land zoning for successful management of groundwater and irrigation in Uttar Pradesh



Source: GW-MATE 2010b; GW-MATE 2011.

4.8. Thick quaternary alluvial sands underlying Lucknow City

4.8.1 Description

Lucknow City on the Central Ganga alluvial plain is underlain by a large thickness of quaternary alluvial sands down to 300m with occasional silty clay aquitards and the occurrence of marginally saline groundwater at 140–200 m depth in the west bank area (Figure 12). The climate is subtropical with an average rainfall of 1,140 mm/year.

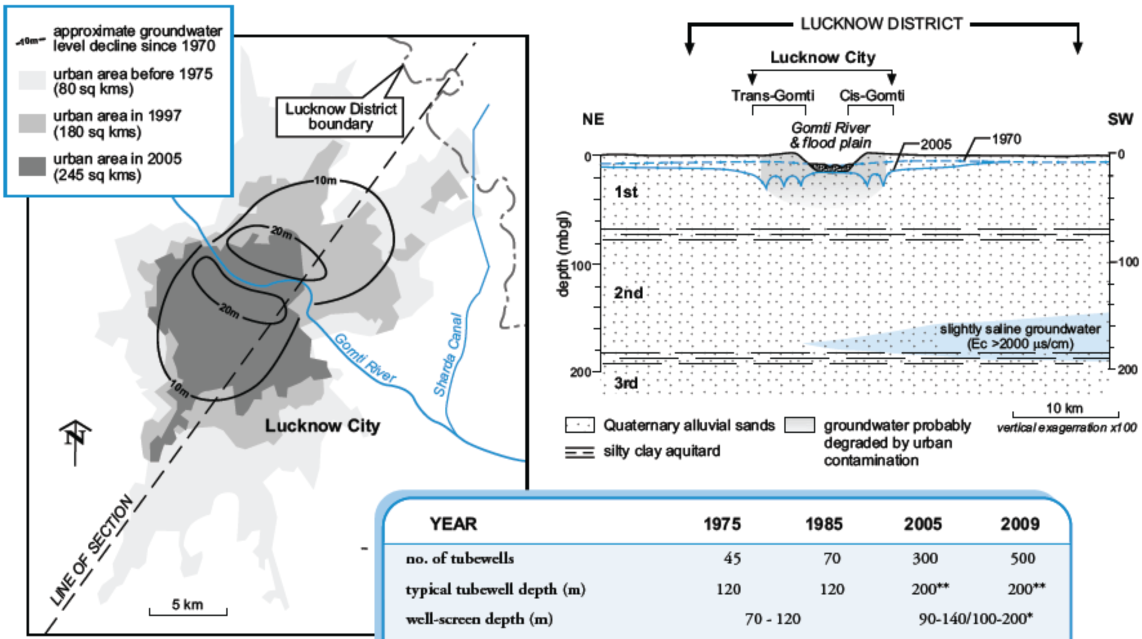
4.8.2 Management issues

In the 1950s, pre-monsoon water-table depths were mainly less than 10 m bgl, but today they have been widely depressed to below 20–30 m bgl. and continue to decline at rates in excess of 1.0 m/year. In consequence, tubewell yields have been reduced significantly because of the highly localized concentration and continuous use of tubewells rather than an overall resource deficiency in the aquifer system. However, all Lucknow Municipal Water Utility (LJS) tubewells deliver raw water quality conforming with current Indian drinking water norms, although private tubewells tapping the “first productive horizon” record elevated NO_3 concentrations (over 100 mg/l), while others have excess dissolved Fe and Mn, suggesting a heavy DOC and N load from wastewater infiltration.

Today the LJS operational position can be summarized as follows:

- Growth in urban demand and water-table decline has resulted in a major public works effort to construct and commission 40 new tubewells per year and to recondition many others.
- Substantial physical leakage losses (estimated around 30 percent overall), especially from older sections of the distribution network, have reduced deployable supply to about 345 Ml/d.
- Source and distribution limitations have resulted in service that is typically 6 hours/day at low pressure with individual use about 100 lpc/day, except in a few areas with better service and some outlying colonies dependent on water tankers.

Figure 12: Lucknow District: hydro geological cross-section, urban growth and groundwater use, 1975–2009



YEAR	1975	1985	2005	2009
no. of tubewells	45	70	300	500
typical tubewell depth (m)	120	120	200**	200**
well-screen depth (m)	70 - 120		90-140/100-200*	
aquifer productive level tapped	2nd	2nd	2nd**	2nd**
typical tube well yields (l/s)	20 - 25		10 - 20	
total municipal groundwater supply (Ml/d)	50	70	190	240

* *differences between cis-Gomti and trans-Gomti areas because of occurrence of slightly saline groundwater*
** *some tubewells drilled to 350m depth to tap 3rd productive aquifer horizon*

Source: GW-MATE 2009c.

4.8.3 Management responses

Municipal water engineers tend to favor reducing dependence on groundwater (because of its operational complexity) and opting for a major new surface water transfer scheme. There are plans to augment further Sardhar Canal flows from the Upper Ghaghara Basin (150 km or so distant) in an attempt to guarantee the availability of 500 Ml/d in all seasons at the city canal offtake, but such a scheme would be highly vulnerable to climate-change impacts (long-term base flow reductions from the Himalayan Mountain chain due to glacier recession) and agricultural sector competition (potential drought conflicts with the farming community across whose land the canal runs).

Moreover, the 2025 demand prediction for Lucknow City requires a gross available supply of 810 Ml/d (before leakage losses are deducted), which would imply maintaining or even expanding local groundwater production. It is thus considered that the robust way to face the future urban water-supply challenge is to look toward a more integrated and harmonized conjunctive use of surface water and groundwater sources, including the development of rural protected well fields within 20 km of Lucknow City; for example, in areas experiencing soil waterlogging as a result of a high and/or rising water table where there would be a secondary benefit of improving land drainage and crop productivity.

5. FINDINGS AND LESSONS LEARNED

5.1. Benchmarking

Table 12 shows the assessment of the feasibility of implementing the actions proposed by GWMATE (GW-MATE 2010a) at the state level by grading a number of benchmarks. Not surprisingly—as happens in most other developing nations and even in emerging and developed countries—technical, legal, and institutional provisions are in a more or less acceptable state but implementation capacity is rather weak.

Table 12: Groundwater governance provisions and capacity benchmarking in selected states

Type of provision/capacity	Checklist criterion	Punjab		Maharastra		Kerala	
		Provision	Capacity	Provision	Capacity	Provision	Capacity
Technical	Existence of basic hydrogeological maps	4	2	4	3	4	3
	Groundwater aquifer delineation	3	1	2	2	3	2
	Groundwater piezometric Monitoring network	2	1	3	3	3	3
	Groundwater pollution hazard assessment	3	1	3	2	3	2
	Availability of aquifer numerical models	1	1	2	1	2	1
	Ground quality monitoring network	2	1	2	1	2	1
Legal /Institutional	Drilling permits / water use rights	3	1	4	2	4	2
	Instruments to reduce GW abstraction	3	1	3	2	3	2
	Instruments to prevent water-well construction	3	1	3	2	3	2
	Sanction for illegal water well operations	3	2	3	2	3	2
	GW abstraction and use charges	2	1	2	2	2	2

Type of provision/capacity	Checklist criterion	Punjab		Maharastra		Kerala	
		Provision	Capacity	Provision	Capacity	Provision	Capacity
	Land use controls on potentially polluting activities	+	+	+	+	+	+
	Levies on generation/discharge of potential pollutants	+	+	+	+	+	+
	Govt agency as “GW Resource Guardian”	2	1	3	2	3	2
	Community aquifer management organizations	2	1	2	1	2	1
Cross-Sectoral Policy Coordination	Coordination with Agriculture Development	3	2	3	2	2	2
	GW-based urban/industrial planning	2	2	2	2	2	2
	Compensation for groundwater protection	+	+	+	+	+	+
Operational	Public participation in groundwater management	3	2	3	2	3	2
	Existence of GW management action plan	1	1	3	2	2	1

Source: Romani 2010, and Sengupta 2010
Notes: 1 = wanting, 2 = incipient/weak , 3 = fair/acceptable but improvable, and 4 = satisfactory. There is no “excellent” ranking because there can always be room for improvement
+ No available information at state level

5.2. Lessons learned about intensive GW use

5.2.1. Intensive groundwater abstraction in hardrock peninsular India:

- The up-scaling and replication of the very positive CBGWM experiences in Maharashtra will necessitate a flexible phased approach which engages experienced support organizations, together with development of a “lighthouse function” in the state government.
- In Tamil Nadu, no matter how merit-worthy in general terms groundwater recharge enhancement measures may be—and their potential as a tool for adaptation to climate change—the extent to which such measures benefit the sustainability of rural water supply sources and the conflicts with existing or potential irrigation wells have to be addressed in each specific application (Table 11).
- In AMC in the drought-prone interior of Maharashtra, a “standing committee on groundwater” drawn from the AMC and relevant state government departments and agencies should be formed

to formulate policy on private groundwater use to bring some organization to the dramatic increase in boreholes.

5.2.2 Intensive groundwater abstraction in the alluvial Indo Gangetic Plain:

- Punjab state’s prohibition on transplanting of paddy rice until June 10 to avoid high evaporation rates has successfully resulted in water saving by eliminating essentially nonbeneficial evaporation. But groundwater abstraction decreased in this case because there were no other significant agricultural water demands. It would be very detrimental to reduce seepage by lining irrigation canals because these water losses help recharge the aquifers.
- Improving groundwater governance would provide options for climate change adaptation: the synergy between groundwater governance improvement and adaptation to climate change has been highlighted in a recent WB study on climate change and in this case study (Table 13).
- Projects in pilot aquifers in the Indo-Gangetic Plain show that both in rural (Punjab paddy fields) and urban (Lucknow City) environments, it is worthwhile to move from spontaneous or incidental to more planned conjunctive use, for both coping with climate change and reducing waterlogging, salinization, and other groundwater quality threats. But, to be successful, planned conjunctive use requires better characterization of underlying aquifers, institutional strengthening and coordination, and raising awareness among farmers and municipal engineers.

Table 13: Climate change adaptation options vis à vis groundwater governance

Climate change adaptation issues	Groundwater governance perspective
Adaptation to climate impacts on groundwater resources in developed and developing countries has not received adequate attention.	*In developing countries such as India the heterogeneous GW governance provisions and general weak implementation capacity has made the task difficult and this will become even more difficult due to the escalating resource demand.*
The Earth's climate is projected to become warmer and more variable, with both increased precipitation and decreased precipitation predicted for different regions.	*Precipitation forecasts for India under the likely climate change scenarios suggest higher but more variable rainfall, except in the drier parts, where rainfall could decrease. The scenarios also predict reduced glacier cover in the Himalayas and associated reductions in the base flows of the Himalayan rivers.*
Compared to surface water, groundwater is likely to be much more compatible with a variable and changing climate.	*The pilot aquifers presented in section 4 of this report illustrate approaches where groundwater has been used to help communities live with a variable climate.*
Groundwater plays a critical role in adapting to hydrologic variability and climate change.	*Managing Aquifer Recharge (MAR) has played an important role in India but recharge enhancement has its pros and cons that must be carefully assessed. Groundwater and surface water conjunctive use can be a very useful adaptation option if it is backed up by close understanding of the water cycle dynamics and judiciously planned.*
Effective decision making: • Effective, long-term adaptation to climate change and hydrologic variability requires measures that protect or enhance groundwater recharge and manage water demand. • Adaptation needs to be informed by an understanding of the local context, and of the dominant drivers (and their projected impact) on groundwater resources • Adaptation options need to be economically viable. In some cases the cost and benefits of an adaptation option may warrant introducing fees/charges for groundwater use, so that an appropriate level of cost recovery is met.	*The GW-MATE pragmatic framework (Section 1.3) was developed through on-the ground experience in a wide range of local contexts and it facilitates communication between the specialist and the decision maker.*

5.2.3 Conjunctive use

The discussion above highlights the fact that conjunctive use needs a good understanding of hydrogeology. Generally, extension of distributaries from canals to areas rich in groundwater discourages tubewells and results in waterlogging. Conjunctive use can also include augmentation tubewells supplementing the low canal surface flows.

The promotion of more planned and integrated conjunctive use has to overcome significant socioeconomic impediments through institutional reforms, public investments, and practical measures, including (a) the introduction of a new overarching state government apex agency for water resources, because existing agencies tended to rigidly follow historical sectoral boundaries and thus tend to perpetuate separation rather than the integration needed for conjunctive use; (b) gradual institutional reform learning from carefully monitored pilot projects; and (c) a long-term campaign to educate farmers through water user associations on the benefits of conjunctive use of both canal water and groundwater, crop diversification, and land micro-management according to prevailing hydrogeologic conditions.

5.3. Lessons learned from coping with groundwater pollution issues

One key conclusion on groundwater quality is that in spite of the complexity of the legal and institutional framework for pollution prevention and control, generally the existing provisions are satisfactory but the implementation capacity is largely ineffective. Nevertheless, much can be learned from the following cases:

- When good communication exists between researchers and decision makers—such as the case of Tamil Nadu Chromate and Chemicals LTD, where sophisticated mathematical models and adequate experimental data contributed to remediating the underlying chromium contaminated aquifer—groundwater quality problems can be solved.
- The uncertainty of the economic viability vis à vis environmental sustainability of implementing technological advancements to achieve zero discharge and recover 85 percent of water used in tannery clusters in Tamil Nadu highlights the need to adequately value groundwater resources and provide some economic incentives for protecting this value.
- Distillery effluents can be used more widely to grow commercial plantations, as shown in Madhya Pradesh.
- Effective communication, as shown in the case of Madhya Pradesh where the Lakes of Bhopal (only source of drinking water) were being polluted by Ganesh idols being immersed, can enable community participation with a respectful approach to their religious beliefs. There are similar experiences with smarter approaches to communications at Pune, where small idols are now immersed instead of big idols, and at Hyderabad where extended idol immersion has been replaced by a quick dip.
- Stakeholder participation in Bhuj City in Gujarat contributed to cleaning a river that had been used as an open drain and polluting the lake used for drinking water. The municipality set up a decentralized wastewater treatment system.

There is also an urgent need for groundwater quality management for sustainable development. There needs to be scientific understanding of hydrogeological controls over naturally occurring minerals in the aquifers. At the same time, pragmatic and urgent measures—similar to the expert groundwater group approach—must be taken gradually with the available information and the existing institutional framework.

5.4. Tailoring groundwater management to each specific typology

The preferred management approaches for each of the four types of circumstances are summarized in Table 14.

Table 14: Preferred management approaches under different aquifer and user typologies

Land use	General and specific hydrogeological environment		Resource use	Policy intervention	Demand management	Recharge	Conjunctive use
Rural	***Hard-Rock Terrains of Rural Peninsular India***	Widespread weathered hard-rock (basalt or granite) aquifers with shallow, low-storage patchy groundwater bodies	Subsistence and commercial agricultural use , drinking water supply, some industries	**Low**	**High**	**Medium**	**Low**
		Occasional but important groundwater bodies in coastal or graben-fill sedimentary aquifers		**High**	**Low**	**Medium**	**Medium**
	Major Alluvial Formations of Rural Indo-Gangetic Plain	Alluvial aquifers, in plains largely within major irrigation canals commands with naturally shallow water table	Mainly subsistence and commercial agricultural exploitations	**Medium**	**High**	**Low**	**High**
		Alluvial aquifers in the older, elevated alluvial plains, with more limited irrigation canals and deeper water table		**High**	**High**	**Low**	**Low**
Urban		Weathered hard-rock aquifers with shallow, low-storage patchy groundwater bodies	Individual urban households, water utilities, industries, tourism	**Low**	**Medium**	**High**	**Medium**
		Major alluvial aquifers in alluvial plains		**Medium**	**Low**	**Low**	**High**

Source: WB 2010, Sec 2-43.

6. GROUNDWATER GOVERNANCE AND CLIMATE CHANGE ADAPTATION

It is useful to review some of the key conclusions of a recent World Bank study on groundwater and climate change (Clifton et al. 2010) with the Indian situation as experienced in the specific cases where GW-MATE has been involved (Table 13).

6.1. Conjunctive use

A key characteristic of conjunctive use is that it usually aims to use the very large natural groundwater storage associated with most aquifers to buffer water-supply availability against the high flow variability and drought propensity of many surface watercourses. As illustrated by the cases of Uttar Pradesh and Lucknow, this makes it especially useful for adapting to climate change impacts, in which the frequency and severity of surface water droughts increase and there are likely to be growing water demands associated with higher ambient temperatures.

6.2. Recharge enhancement

While the incremental enhancement of groundwater resources that can be achieved by artificial recharge measures is significant in terms of the demand represented by rural drinking water supply, it will often not be sufficient to meet the much larger demand from irrigation water wells. Thus for a long-term trend in aquifer depletion to be reversed, a more integrated approach is required that includes both optimization of recharge enhancement and use of complementary demand-side management actions.

7. RECOMMENDATIONS

7.1. Recommended actions for intensive groundwater abstraction

Recommended implementation actions for managing intensive abstraction under different GW settings in India are summarized in Table 15.

Table 15: Recommended implementation actions

Land use	General and specific hydrogeological environment	Resource use	Implementation Actions
Rural	***Hard-Rock Terrains of Rural Peninsular India***	Widespread weathered hard-rock (basalt or granite**)** aquifers with shallow, low-storage patchy groundwater bodies	1. Enable and nurture community-based groundwater management, strongly complemented by availability of demand management interventions. 2. Encourage artificial recharge. 3. Explore technical interventions (e.g. separate agriculture electricity feeders) to indirectly control energy costs and groundwater pumping.
		Occasional but important groundwater bodies in coastal or graben-fill sedimentary aquifers	1. Enable and nurture community-based groundwater management, strongly complemented by availability of demand management interventions. 2. Encourage artificial recharge. 3. Explore technical interventions (e.g. separate agriculture electricity feeders) to indirectly control energy costs and groundwater pumping. 4. Maintain regulation in most critical aquifers.
	Major Alluvial Formations of Rural Indo-Gangetic Plain	Alluvial aquifers, in plains largely within major irrigation canals commands with naturally shallow water table	1. Major emphasis on microzone-based conjunctive use management (in canal head: seal canal breaches; groundwater pumping; sodic/saline land reclamation; in tail end; promotion of water-efficient high-value crops). 2. Explore technical interventions (e.g. separate agriculture electricity feeders) to indirectly control energy costs and groundwater pumping. 3. Maintain regulation in most critical groundwater blocks.
		Alluvial aquifers in the older, elevated alluvial plains, with more limited irrigation canals and	1. Major emphasis on microzone-based conjunctive use management (in canal head: seal canal breaches; groundwater pumping; sodic/saline land reclamation; in tail end; promotion of water-efficient

		deeper water table	high-value crops). 2. Support technical interventions for demand-side management in high-water use crops. 3. Explore technical interventions (e.g. separate agriculture electricity feeders) to indirectly control energy costs and groundwater pumping. 4. Maintain regulation in most critical groundwater blocks.
Urban	***Urban Environment***	Weathered hard-rock aquifers with shallow, low-storage patchy groundwater bodies	1. Assess the extent of prevalent private self supply through groundwater and account for it in planning and costing of new water supply augmentation schemes. 2. Promotion of urban demand-side management. 3. Promotion of household rainwater harvesting measures. 4. Maintain regulation in most critical groundwater blocks.
		Major alluvial aquifers in alluvial plains	1. Plan conjunctive use where exploitable surface water supplies are available. 2. Spread groundwater capture over a large area by developing easily manageable and protected peripheral well fields. 3. Integrate groundwater development and management into overall urban planning.

Source: WB 2010, Sec 5-90.

7.2. Recommended actions for protecting against groundwater pollution in India

With modern technologies, awareness at both government and public levels, political willingness at the highest level, transparency, corruption prevention and enforcement, the problem of groundwater pollution in India can be effectively solved. The challenge is to find a roadmap to achieve this goal.

Table 16 summarizes the recommended generic measures to address the main groundwater pollution issues. The assessment in the last two columns shows that although the required legal and institutional provisions are mostly in place, the level of implementation capacity is wanting.

Table 16: Recommended measures to address main groundwater pollution issues

	RECOMMENDED MEASURES	Provision	Capacity
INLAND SALINITY			
Inherent salinity	Regulation, rain water harvesting and water conservation, irrigation management, deep aquifer development in upper reaches and conjunctive use	3	2
Water loggin under surface irrigated areas	Conjunctive use	3	3
COASTAL SALINITY			
Saline Ingress	Water conservation measures like sub-surface dykes	3	1
Sea water intrusion	Engineering/barieer dependent techniques, regulation, monitoring and assessment of intrusion	3	1
GEOGENIC			
Arsenic	Development of deep aquifers free of arsenic, rainwater harvesting, piped surface water supply, quality improvement with survace water, arsenic removal plants	3	2
Flouride	Rainwater harvesting and water conservation, various deflouridation techniques	3	2
Iron	Rainwater harvesting and water conservation, various deironization techniques	3	2
ANTHROPOGENIC			
Mining	Scientific workplan for storage and disposal of ores and wastes, treatment techniques specifically for reduction of Cr(VI) to Cr (III)	3	2
Industrial	Effective monitoring and regulation, treatment of waste and safe disposal, beneficial use of effluents, use of mathematical models for aquifer remediation	3	2
Tanneries	Effluent treatment, effective monitoring and regulation	3	2
Distilleries	Effluent treatment, effective monitoring and regulation	3	2
Land fills and garbage dumps	Hydrogeological studies for site selection, sanitary landfills, and garbage dumps with impermeable barriers	3	1
Agriculture	Raise awareness for specific areas in quantity-time-frequency –application of fertilizers and pesticides	2	1
Lack of/poor sanitation	Control of flow of untreated industrial and domestic wastes through water courses and unlined channels to rivers, intensify rural sanitation and health education	2	1

Notes: 1 = wanting, 2 = incipient/weak, 3 = fair/acceptable but improvable, and 4 = satisfactory.

7.2.1 *Pilot project approach*

The International Workshop on Groundwater Protection Report advised that an incremental learning approach should be adopted using existing institutional structures. Pilot projects could be established in prevention and control for different pollution sources under different aquifer typologies, before moving ahead with institutional strengthening using a “parallel track approach.” The preliminary analysis of groundwater quality issues points to initially strengthening the SPCB. Coordination among all state and central-level relevant agencies could then be strengthened if the pilot experiences confirmed the need for this.

Some specific recommendations stemming from the preliminary analysis are (a) learn from international experience dealing with emerging pollutants; (b) expand the achievements in groundwater quality monitoring under the WB-supported Hydrology Project-I; (c) enlarge the Hydrology Project-II to cover groundwater pollution; (d) clarify responsibilities for groundwater quality monitoring of related state groundwater and pollution control state agencies; (e) establish an effective groundwater quality monitoring network in coastal regions to keep track of the landward movement of the seawater/freshwater interface, including “sanctuary wells” to be used for drinking water supply during cyclones and tsunamis; and (f) assess the cost of making arsenic and fluoride standards stricter, following the international trend (Chakraborti et al 2011).

7.3. Recommended action for strengthening the State Groundwater Development and Management agencies

Institutional capacity is the weakest link of all the elements in the groundwater governance chain. Although some degree of community self-regulation is required, government capacity to enable and nurture self-regulation must be strengthened.

While groundwater management takes place at the local level, constitutionally the state governments are in effect guardians of this resource and they are in a better position to (a) facilitate cross-sectoral coordination of groundwater resources at the most critical (state) level; (b) promote government-stakeholder interaction, especially considering that most state government departments have operational offices at district level, where many of the local management measures will need to be taken; and (c) design groundwater management approaches specific to the typologies and user needs of local aquifers.

However, groundwater agencies in the states are not adequately equipped to take up these roles. These agencies are located at relatively low levels in the state hierarchy and tend to have much less clout than their counterpart departments focused on, for example, irrigation or water supply. In many cases, there is no dedicated state groundwater agency. The organizational structure, resources, and staff skill sets continue to be oriented primarily toward groundwater development rather than management.

Groundwater management is more about enabling the users to manage interactions among themselves than it is about top-down managing of a natural resource, and a transformational shift will be needed to reflect this in the functioning of state groundwater agencies. This should be addressed as a priority. Maharashtra provides a good example (GW-MATE 2007) of taking the initiative on this front. The technical resources and staff competencies of the state Groundwater Survey and Development Agency are being strengthened through various programs, including support from World Bank-financed projects.

The capacity of state groundwater institutions will need to be developed to ensure that they can perform the key functions of providing information and technical support, enabling community management, and enforcing regulatory measures. The structure of state groundwater development and management agencies should derive from these key functions. Table 17 present a broad outline of how these functions could be formalized in a state groundwater institution.

With community groundwater management emerging as the most viable model, at least in the hard-rock areas, it is important to ensure that community-based initiatives get the required support from the state groundwater agencies during the time that it takes for the communities to genuinely become capable of managing sustainable groundwater management regimes. For this reason, the community management enabling function is the most critical change needed within state groundwater agencies. The regulatory function also merits strengthening for large users or clusters of small users where agreed regulations are the only way out to ensure equity within heterogeneous users communities.

Recent experience from community groundwater management pilots being implemented under two World Bank projects in Maharashtra (GW-MATE 2007) highlights the importance of expanding the skills profile in the state groundwater agency by going beyond the technical and monitoring functions to include a management enabling function. More importantly, this example demonstrates that with the right support these internal organizational changes can be readily implemented and can produce tangible results.

Although dedicated state groundwater management agencies are desirable, this may not be possible in many states. A pragmatic and organic approach would be needed to ensure that the key functions are performed through organizational arrangements appropriate to each state's local context. For example, in Andhra Pradesh (GW-MATE 2009b), the Department of Rural Development, with its track record of success in community development initiatives, could work closely with the Groundwater Department for facilitating community groundwater management.

Where the groundwater agency is located in the state hierarchy is another crucial element of the solution. It is of foremost importance that the state groundwater agency be located at an appropriate level in order for it to participate in and influence the dialogue on the important aspects of state (and even national) policy on irrigation, agriculture, energy, land planning, and rural and urban development. Since surface water and groundwater are intimately connected, planning and management of surface water and groundwater should be closely integrated through a focus on conjunctive use. The proposal currently under consideration in Maharashtra to bring surface water and groundwater under the purview of the state water resources regulatory authority is a welcome example in this regard, as long as the state groundwater agency is located at the appropriate level.

Successful implementation also depends on: (a) political commitment at the highest level; (b) acknowledging that parallel to implementing groundwater policies and organizational arrangements, governments at the central and state levels should urgently implement transition measures to a substantially less water-demanding economy in some critical blocks to reduce the risk of permanent deterioration, where the only option is "orderly depletion;" and (c) acknowledging the fact that

SGWDMAs are imbedded into a macro political and economic system and therefore, parallel to implementation, an open dialogue with the Union level must be established to release some paralyzing restrictions and grant the required support to SGWDMAs so they in turn can effectively become champions of CBGWM.

Table 17: Suggested missions and functions for individual units within a state GW management agency

Organizational unit/Mission*	Main Functions
Groundwater Information and Planning Unit (GIPU) *Keeping updated resource and user status aimed at contributing to sustainability and replicability of groundwater management initiatives*	• Delineation of main groundwater bodies and priorities for promotion of CBGWM (including relationship with watersheds) • Hydrogeological & socioeconomic planning framework for replication & up-scaling strategy and identification of new GWCBM initiatives, distinguishing essentially drinking water from resource management needs • Identification of critically endangered groundwater blocks to be notified • Evaluation of resources of main "groundwater bodies" • Establishing permanent policy dialogue with other sectors and state agencies • Post-project "lighthouse" overview to focus on issues that put sustainability at risk** • Overall planning and preparation of procedures, guidelines, and standards • State data basing, GW allocation & granting of entitlements to selected users • Conducting capacity building/awareness raising programs for GW users, NGOs, stakeholders, politicians, bureaucrats, professionals, and technicians
Groundwater Survey, Development & Demand Management Unit *Ensuring that GW supply, recharge enhancement and demand management measures are scientifically sound, economically reasonable, follow best professional practice, and are properly linked to water providers*	• Traditional hydrogeological surveying and improved GW quantity & quality monitoring • Keeping updated GW users inventory and GW uses profiles • Ensuring quality-control/quality-assurance of construction, O&M and agricultural/irrigation (and generally demand-management) activities/outputs • Undertaking permanent critical technical/economic assessment and obtaining field evidence for updating guidelines for recharge enhancement measures • Ensuring formal linkages with irrigation/water supply project are conducted
Groundwater Management Enabling	• Keeping links with relevant panchayats • Coordinating CBGWM pilot projects and establishing a nursery

Organizational unit/Mission*	Main Functions
Unit *Contributing to communities in CBGWM initiatives becoming leaders of socially and sustainable development processes*	for CBGWM initiatives • Keeping the necessary links with other government agencies/external support agencies to ensure that GW users have access to inputs for making efficient and beneficial use of the reource • Maintaining linkages with and capacity building of SOs (first supporting design and implementation of CBGWM initiatives, and later as part of lighthouse outreaching capacity) • Keeping a benchmarking system aimed at constructive competition among CBGWM projects
Groundwater Management Regulatory Unit *Supporting local authorities in dealing with critically endangered groundwater blocks*	• Traditional hydrogeological surveying and improved GW quantity & quality monitoring • Keeping updated GW users inventory and GW uses profiles • Keeping links with and capacity building of relevant panchayats, local authorities and district comptrollers • Establishing agreements with local authorities to decentralize nonauthority enforcement functions • Undertaking regulatory enforcement

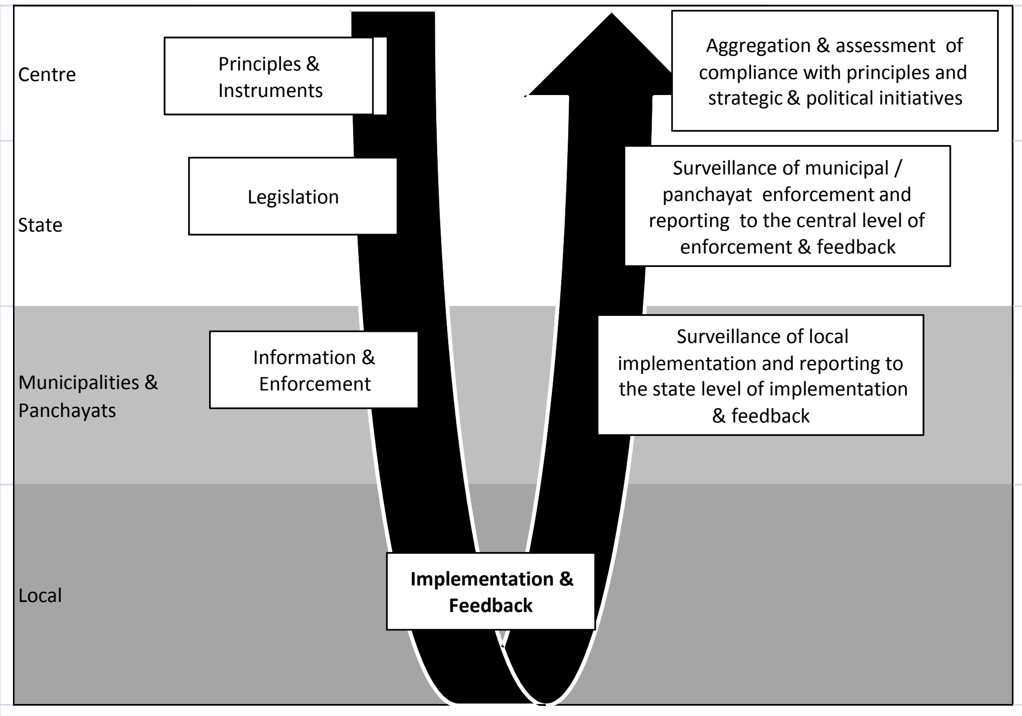
Source: WB 2010, Sec. 5.1
Notes: *While GIPU should remain central (at state level) because of the need to maintain a minimum critical mass and high professional quality, the other units could maintain a small core coordination group (also at central level) but all operational activities should be delegated at the district level where some aquifer problem merits being addressed or where some preventive measure is advisable.
** This is the most important of the proposed functions since a “government lighthouse” for monitoring CBGWM initiatives (aided by NGOs playing the role of SOs, if required) is indispensable to ensure that they do not fail because of lack of support and control while communities become leaders of a socially/environmentally sustainable development process.

8. ANNEXES

8.1. Recommendations from the International Workshop on Groundwater Protection Report[2]

It is recommended that the required instruments be developed through the roadmap shown in Figure A-1:

Figure A-1. Roadmap to improve groundwater protection instruments in India



Source: EU 2010.

It is furthermore indicated that the following actions are recommended for consideration with respect to policies, strategies and institutional aspects:

- Aggregate all groundwater monitoring under a nodal agency, contributing to integration of monitoring programs into one cost-efficient program.
- Strengthen existing policy instruments pertaining to well registration and permits through proper surveillance, contributing to abstraction reduction or recharge increase.
- Promote capacity building and training programs for governments and NGOs, enhancing implementation efficiency and public participation.
- Outsource operation of monitoring to external laboratories under public contract and control.
- Include EU monitoring prioritization methodology, contributing to integration into one-cost efficient program.

[2] Held in New Delhi during September 14 and 15, as part of the EU-India Action Plan support Facility – Environment, funded by The European Union and organized by the WB Hydrology Project, DHI Water & Environment and Mott MacDonald. Presentations and workshop report downloadable from http://www.apsfenvironment.in/component/content/article/78. This Annex summarizes EU (2010).

- Enhance public awareness of groundwater as owned by one but affecting many, contributing to abstraction reduction or recharge increase.
- Promote separate power feeder lines for irrigation, as in Gujarat, to other states in India, to remedy outdated and inappropriate economic incentives to reduce abstraction.

Table A-1. Groundwater protection instruments with a "testing step" approach

Instrument targeted by action	Beneficiary	Development step	Testing step	Overall objective
Distributed management model	Centre, MoEF	Development of guidance for management of industrial and landfill discharges including principle formulation, identification of legislative elements, information material, communication media and models for reporting and action	Implementation and evaluation of the guidance document within the pollution control sector under the MoEF from CPCB to industry/landfill	Enhanced enforcement of water and environmental legislation
Monitoring and dissemination instrument	Centre, MoEF and MoWR	Merger of Indian and EU monitoring guidance, including prioritization of aquifers and parameters for monitoring, data aggregation, interpretation and presentation, dissemination methods and methods for implementation in planning and enforcement of regulations	Implementation and evaluation of the guidance for a large aquifer system from planning to dissemination and data exploitation in planning	Enhanced knowledge, dissemination and utilization of the true state of the groundwater resource
Systematic control and self monitoring instrument	States	Development of self monitoring guidance including parameter selection, point of compliance identification, criteria setting references, selection of methods for sampling and analysis, frequency setting, external auditing requirements, follow up planning etc	Implementation and evaluation in one or two representative states for one or two sectors such as pharmaceutical industry and landfills	Reduced industrial discharges, directly or indirectly, to groundwater due to enhanced control
Economic incentives instrument	States	Development of a guidance document for economic incentive application in rural sectors based upon the principle of separate power feeder lines, subsidy, registration and permits	Evaluation of the guidance document against the Gujarat pilot implementation done previously	Reduced and more equally distributed groundwater consumption for irrigation
Co-management instrument	Panchayats	Development of a model for co-management of water abstraction and pesticide/fertilizer application with education methods, shared decision models and clarification of regulatory implications	Evaluation of the model against pilot implementation of co-management at village level done previously	Reduced pollution of groundwater with fertilizers and pesticides
Awareness building	Local	Development of templates and methods for interactive awareness raising on irrigation, pesticide application and fertilization based upon the Village Resource Centres approach	Evaluation of the model against the pilot implementation of satellite based village communication and public education at village level being done previously	Reduced groundwater consumption and nitrate/ fertilizer pollution due increased understanding of the issue
Artificial recharge	States	Review of previously conducted recharge pilot projects, quantitative assessment of benefits and disadvantages, aggregated into guidance on recharge design for different Indian scenarios	Evaluation of the guidance document against selected, representative pilot recharge projects done previously.	Enhanced infiltration of rainwater during monsoon events
Safeguard/ well head protection zones	States	Development of guidance for selecting, delineating, protecting, monitoring and reacting in safeguard zones in areas of drinking water interest	Implementation and evaluation of the guidance for a large aquifer system from selecting to reacting upon monitoring of development in safeguard zones	Reduction of number of wells to be abandoned due to pollution

8.2. Key policy and legal provisions relevant to groundwater pollution protection

Key Policy/Legal Provision	
NEP 2006	Response to constitutional commitment to clean environment. Inter-related actions regarding quantity: (a) energy pricing impacts (b) efficient water use (c) GW Maps (d) recharge enhancement (e) scientifically-based GW regulatory plan (f) As FI and other toxics removal for rural drinking water (g) Improve water use productivity (h) scientifically-based location of dumping sites (i) optimize use of fertilizers, pesticides and insecticides.
NWP 2002	(a)GW quality, especially polluter-pays principle and effluents to meet the prescribed standards and (b) users and other stakeholders –especially Gram Panchayats participation in GWR management
BW MHR 1998	Specify the concerned SPCBs as the prescribed authority to implement the rules in which deep burial is stated as an option for human anatomical and animal waste only for towns with population less than 500,000 and in rural areas. Standards for deep burial are prescribed which address protection of groundwater quality and prohibits shallow well nearby the site.
CJ	Right to life enshrined in the constitution has been interpreted by the courts in India, especially in the Honorable Supreme Court has at all times protected the rights of citizens for clean water and environment to include right of citizen to clean water and environment.
CRZN 2010	Bill 2010 tabled to overcome difficiencies in 1991 Act (a) CG to direct SGs to prepare action plans to mitigate discharge into the coast of untreated waste effluents, sewerage including solid. Necessary budget to deal with pollution related activities shall be provided by SGs and implemented by it. CPCB shall monitor the implementation.
EPA 1986	Provide for protection and improvment of environment, including water, air land and their inter-relationship and with human being, other living creatures, plants, micro-organism and property. Covers harzardous wastes and chemicals, environmental impact assessment process. Bestows powers on the CG to constitute authorities to deal with specific environmental issues or areas.
HW MHR 1989	Provides for generation, collection, reception, treatment, storage and disposal of waste listed as harzardous in it, as well as harzardous waste import for recycling.
IA 1968	Regulates the import, manufacture, sale, transport, distribution and use of insecticide with a view to prevent risk to human beings or animals. However, it refers to prevention of risk to human beings and animals and does not refer to the environment, but approval of PMB 2008 below will

Key Policy/Legal Provision	
	address this issue.
NGTA 2010	Any person aggrieved by orders passed on environmental matter under the WPCPA 1974 & EPA 1986 can appeal to the Tribunal. Appeal against any order passed by the Tribunal lie only with the Supreme Court.
PMB 2008	In addition to issues covered by IA 1968 includes prevention of risk to the environment. When passed, will repeal IA 1968 and the institutions then rightfully responsible for groundwater quality , armed with data on undesirable levels of pesticides if any, can seek banning of the manufacture or import of the culprit
PRA	The Constitution (Seventy third Ammendment) Act, 1992 provides that there shall be constituted in every State, Panchayats at the village level, intermediate and district level. The legislature of a State by law, may endow the Panchayats with such power and authority as may be necessary. The States legislature may pass regulations on the authority of the Panchayat on the 29 listed subjects, who are expected to develop economic and social development plans.
SGWACs	CG has circulated sate GW Model bill, but the Acts and Authorities created under ot are primarily concerned with GWR quality management.
SWMR 2000	Requires municipalities are to establish solid waste processing and disposal facility including land fills after getting authorization from SPCBs. SPCBs are required to periodically GW quality within 50 meters of the landfill site. The rules contain specifications for landfill, including for pollution prevention measures such as linear material, thickness, collection of leacheate and its treatement so that groundwater quality is not adversely impacted.
WPCPA 1974	Central Act adopted by all the States to provide for the prevention and control of water pollution and the maintaining or restoring of wholesomeness of water and for establishment of SPCBs for implementing said purposes. Prohibits use of stream or well for disposal of polluting matter and SPCBs can take action under penal provisions in the Act.
WPCPA 1977	Levy and collect a cess on water abstracted by certain industries and by local authorities to argument the resources of CPCB and SPCBs. SPCBs collect the cess, remit it to CG, which later reimburses SPCBs. There is a case for consideration to reimburse atleast part of the collected cess amount to the respective Panchayat as and when they are entrusted with protection of quality of water resources within their jurisdiction.

Source: Sengupta 2010.

8.3. Preliminary survey of Indian universities and institutes relevant to GW management and protection

Names of universities and IITs	Subject	Type of Degree
Indian School of Mines University, Dhanbad,	Applied Geology	Five Year Integrated M.S.C (Tech), Post Graduate degree and Ph.D
Sri Venkateswara University, Thirupathi, Andhra Pradesh	Geology Hydrogeology	M,S.C degree in Geology M.S.C degree in Hydro-Geology since 2006-2007
AP University, Andhra Pradeh		
Vizianagaram	Geology	B.S.C
Vishkapatnam	Applied Geology	M.S.C
Tirupathi University	Applied Geology	M.S.C
Patna University, Bihar	Geology	M.S.C
Pondicherry University, Pondicherry	Geology / Applied Geology under Earth Sciences	M.S.C
Delhi University	Geology	M.S.C
Mysore University, Mysore, Karnataka	Geology	B.S.C & M.S.C
Aizal University, Mizoram	Geology	M.S.C
Chennai University, Tamilnadu	Geology	B.S.C, M.S.C, & P.H.D
University of Uttaranchal	Applied Geology	M.S.C
Kolkatta University, West Bengal	Geology	B.S.C
IIT s		
IIT, Mumbai	Hydro-Geology	M.Tech
IIT, Kharagpur	Applied-Geology	M.Tech
IIT, Roorkee	Geology	B. Tech & M.Tech
Aligarh Muslim University , UP	Hydrogeology	Post graduate Diploma
Annamalai University , Chennai	Hydrogeology	Correspondence course in Post graduate Diploma
University of Calcutta	Geology	Post Graduate studies
Banaras Hindu University	Geology	BSC (Hons) and MSC
Dr Harisingh Gaur University (Formerly Sagar University) Madya Pradesh	Geology and Applied Geology	M Tech

Names of universities and IITs	Subject	Type of Degree
NGRI (National Geophysical Research Institute), Hyderabad, India	Groundwater in hard-rock areas	cogoverns the Indo-French Centre for Groundwater Research (IFCGR)

Source: Garduño et al 2009.

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